APPENDICES

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APPENDIX A. SEA-LEVEL RISE SCIENCE AND PROJECTIONS FOR FUTURE CHANGE

A.1. Global Drivers of Sea-Level Rise

The main mechanisms driving increases in global sea level are: 1) expansion of sea water as it gets warmer (thermal expansion) and 2) increases in the amount of water in the ocean from melting of land-based glaciers and ice sheets as well as human-induced changes in water storage and groundwater pumping (Chao et al., 2008; Wada et al., 2010; Konikow, 2011).[26] The reverse processes can cause global sea level to fall.

A.2. Local Drivers Sea-Level Rise

Sea level at the regional and local levels often differs from an average global sea level.[27] The primary factors influencing local sea level include tides, waves, atmospheric pressure, winds, vertical land motion and short duration changes from seismic events, storms, and tsunamis. Other determinants of local sea level include changes in the ocean floor (Smith and Sandwell, 1997), confluence of fresh and saltwater, and proximity to major ice sheets (Clark et al., 1978; Perette et al., 2013).

A.3. Factors Influencing Sea-Level Rise in California

As described above, sea-level rise will vary locally and regionally. Over the long-term, sea level trends in California have generally followed global trends (Cayan et al., 2009; Cayan et al. 2012). The 2012 "Climate Change and Sea Level Rise Scenarios for California Vulnerability and Adaptation Assessment" from the California Climate Change Center, assumes "that sea-level rise along the Southern California coast will be the same as the global estimates" (Cayan et al., 2012). The 2011 OPC Interim Guidance on Sea-Level Rise also applied global sea level projections to coastal California, recommending specifically that state agencies consider projections of sea-level rise developed from recent semi-empirical global sea level projections (Vermeer and Rahmstorf, 2009).

However, global projections do not account for California's regional water levels or land level changes. California's water levels are influenced by large-scale oceanographic phenomena such as the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO), which can increase or decrease coastal water levels for extended periods of time. Figure 7 shows how El Niño and La Niña events have corresponded to mean sea level in California in the past. California's land levels are affected by plate tectonics and earthquakes. Both the changes to water levels and changes to land level are important factors in regionally down-scaled

[26] Large movements of the tectonic plates have been a third major mechanism for changes in global sea level. The time periods for plate movements to significantly influence global sea level are beyond the time horizons used for even the most far-reaching land use decisions. Plate dynamics will not be included in these discussions of changes to future sea level.
[27] For further discussion of regional sea level variations and regional sea-level rise projections, see, for example, Yin et al. 2010, Slangen et al. 2012, Levermann et al. 2013.

projections of future sea level. For these reasons, sea-level rise projections specific to California are more relevant to projects in the coastal zone of California than projections of global mean sea level.

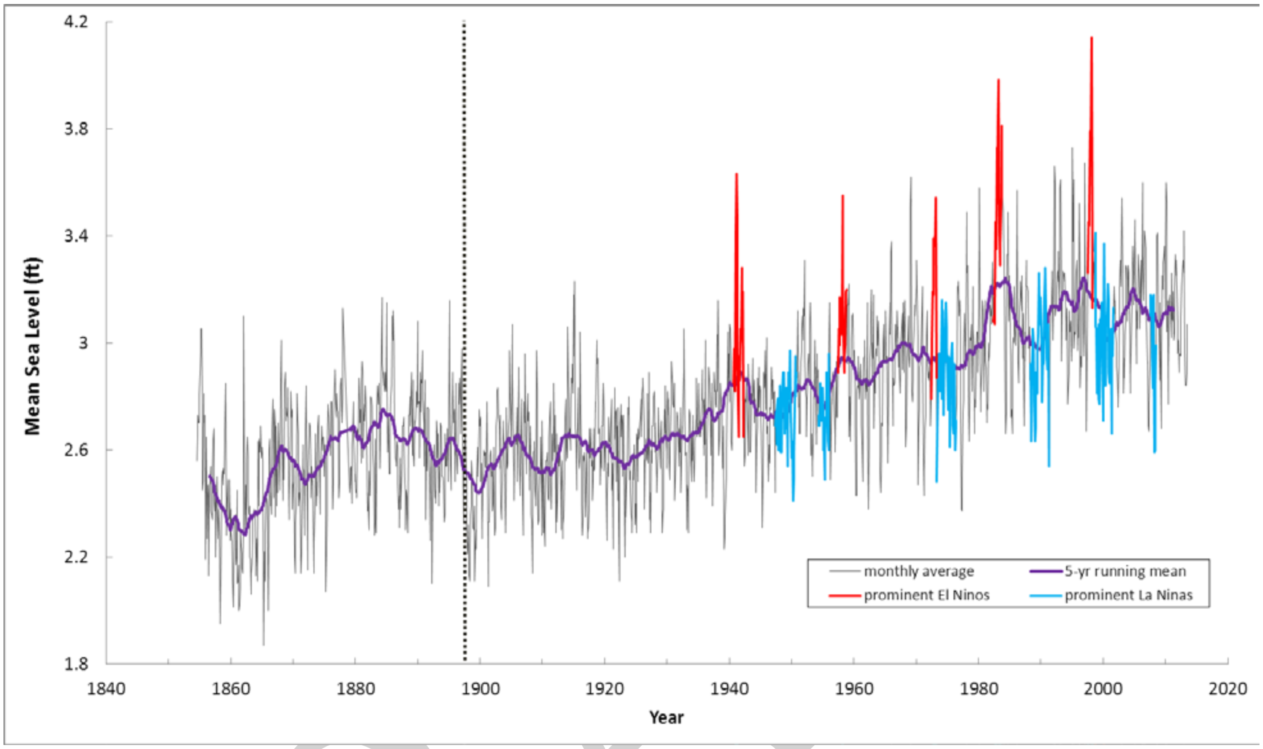

Figure 7. Variations in monthly mean sea level, Fort Point, San Francisco, 1854 to 2013. Mean sea level heights (in feet) are relative to mean lower low water (MLLW). Purple line represents the 5-year running average. Note that the monthly mean sea level has varied greatly throughout the years and the several of the peaks occurred during strong El Niño events (red highlight). Periods of low sea level often occurred during strong La Niña events (blue highlight). The current "flat" sea level condition can also be seen in the 5-year running average. Sources: NOAA CO-OPS data, Station 9414290, http://tidesandcurrents.noaa.gov/ (sea level); NOAA Climate Prediction Center, http://www.elnino.noaa.gov/ (ENSO data).

A.4. Approaches for Projecting Future Global Sea-Level Rise

This section provides an overview of some of the more well-known approaches that have been used to project sea level changes and their relevance to California. Appendix B will cover how these projections can be used to determine water conditions at the local scale.

There is no single, well-accepted technique for projecting future sea-level rise. Understanding future sea-level rise involves projecting future changes in glaciers, ice sheets, and ice caps, as well as future ground water and reservoir storage. Two subjects in particular present challenges in sea-level rise modeling. First, future changes to glaciers, ice sheets, and ice caps are not well understood and, due to the potential for non-linear responses from climate change, they present many difficulties for climate models (Overpeck, 2006; Pfeffer et al., 2008; van den Broecke et al., 2011; Alley and Joughin, 2012; Shepherd et al., 2012; Little et al., 2013). Second, the actual magnitudes of the two human-induced changes – pumping of groundwater and storage of water in reservoirs – are poorly quantified, but the effects of these activities are understood and can be modeled (Wada et al., 2010). Despite these challenges, sea-level rise projections are needed for many coastal management efforts and scientists have employed a variety of techniques to model sea-level rise, including:

1. Extrapolation of historic trends;
2. Modeling the physical conditions that cause changes in sea level; and
3. Relating sea level to other climatic conditions that can be fairly well projected (empirical or semi-empirical method).[28]

There are strengths and weaknesses to each approach, and users of any sea-level rise projections should recognize that there is no perfect approach for anticipating future conditions. This section provides users of the Guidance document with a general understanding of several of the most widely used sea-level rise projection methodologies and their respective pros and cons. For reference, the 2012 NRC Report, which is considered the best available science at present, used a combination of the latter two techniques.

A.4.1. Extrapolation of Historic Trends

Extrapolation of historic trends in sea level has been used for many years to project future changes in sea level. The approach assumes that there will be no abrupt changes in the processes that drive the long-term trend, and that the driving forces will not change. Because drivers of climate change and sea-level rise, such as radiative forcing, are known to be changing, this method is no longer considered appropriate or viable in climate science.

A recent modification to the historic trend method discussed above has been to estimate rates of sea-level rise during the peak of the last interglacial (LIG) period (~125,000 years before present, when some drivers of sea-level rise were similar to those today)[29] based on proxy records and apply those sea-level rise rates to the 21st century. For example, Katsman et al. (2011) and Vellinga et al. (2008) used the reconstructed LIG record of sea level change (from Rohling et al., 2008) to reconstruct sea-level rise rates during rapid climate warming, and applied these rates to estimate sea level at 2100 and 2200. Similarly, Kopp et al. (2009) used sea-level rise rates inferred from the LIG to estimate a range of sea-level rise for 2100 between 1.8 – 3.0 feet (0.56 - 0.92 m). Compared to traditional historic trend extrapolation, this modified approach has the advantage of including the dynamic responses of ice sheets and glaciers to past global climates

[28] Another approach to projecting sea-level rise is to use "expert judgment" (AMAP, 2011; Bamber and Aspinall, 2013). The AMAP 2011 report surveyed the literature to construct a range of estimates of SLR by 2100, and then had a panel of experts decide on a smaller "plausible range", which not surprisingly falls right in the middle of the ranges shown in Fig. A-1. Bamber and Aspinall (2013) used statistical analysis of a very large number of expert estimates of future SLR to come up with their projected ranges. This approach will not be discussed further in this section.

[29] During the last interglacial, global mean temperature was 1-2ºC warmer than the pre-industrial era (Levermann et al. 2013), while global mean sea level was likely 5 – 9 m above present mean sea level (Kopp et al. 2009; Dutton and Lambeck 2012; Levermann et al. 2013).

that were significantly warmer than the present, but is limited by the large uncertainties associated with proxy reconstructions of past sea level.

A.4.2. Physical Models

Physical climate models use mathematical equations that integrate the basic laws of physics, thermodynamics, and fluid dynamics with chemical reactions to represent physical processes such as atmospheric circulation, transfers of heat (thermodynamics), development of precipitation patterns, ocean warming, and other aspects of climate. Some models represent only a few processes, such as the dynamics of ice sheets or cloud cover. Other models represent larger scale atmospheric or oceanic circulation, and some of the more complex General Climate Models (Climate Models) include atmospheric and oceanic interactions.

The Intergovernmental Panel on Climate Change (IPCC) is one of the main sources of peer-reviewed, consensus-based information on climate change. The IPCC does not undertake climate modeling, but uses the outputs from a group of climate models that project future temperature, precipitation patterns, and sea-level rise, based on specific emission scenarios. Seven of the 16 Models used in the IPCC's 4th Assessment Report (2007)[30] provided projections of sea-level rise, and from these models, the IPCC (2007) projected an increase in average global sea level of 7 inches to 23 inches (18 cm to 59 cm) from the time period of 1980 – 1999 to the time period of 2090 – 2099. However, the IPCC elected not to account for dynamic changes in continental ice volume (glaciers and ice sheets) in its sea level projections, stating, "*Dynamical processes related to ice flow not included in current models but suggested by recent observations could increase the vulnerability of the ice sheets to warming, increasing future sea level rise. Understanding of these processes is limited and there is no consensus on their magnitude.*" (IPCC 2007, Table SPM-3). The projections include contributions from ice sheet melt based on historical rates of melt, but do not include estimates of sea-level rise change from increased rates of ice sheet melt because there was only limited understanding of such processes at the time of the report (IPCC 2007). As a result, the IPCC projections from the 4th Assessment Report are thought to underrepresent future sea-level rise.

One outcome from the 2007 IPCC report was the realization that there was a need for focused study and modeling of ice dynamics. As an initial effort to better estimate the contributions of ice flows to sea-level rise, climate researchers and glaciologists attempted to determine the upper limit of possible glacier-melt contributions to sea level over several decades, based on the physical constraints of specific glacier systems. A study by Pfeffer, Harper and O'Neel (2008) looked at the plausibility of a rapid rise in sea level from glacial and possible scenarios of polar ice melt. They determined that discharge rates from Greenland glaciers would need to range from 26.8 to 125 km/yr (16.7 to 78 mi/yr), starting immediately and being sustained through 2100, to cause a 2- or 5-m (6.6 to 16.4 ft) rise in sea level by 2100 (Pfeffer et al., 2008). These rates are larger than ever observed even at peak discharges. The researchers do not dismiss the possibility that this discharge could occur, but conclude, "Although no physical proof is offered that the velocities (for a 2- to 5-meter sea-level rise by 2100) cannot be reached or maintained

[30] The most recent Assessment Report as of the time of this document.

over century scales, such behavior lies far beyond the range of observations and at the least should not be adopted as a central working hypothesis" (Pfeffer et al., 2008, pg. 1342). Pfeffer et al. (2008) also project sea-level rise ranging from about 0.8 to 2.0 m (2.6 to 6.6 ft) by 2100, based on the several scenarios of likely ice flow dynamics. This eustatic rise is based on a 0.3 m (1 ft) rise from thermal expansion and between 0.5 to 1.7 m (1.6 to 5.6 ft) from ice dynamics (Pfeffer et al., 2008). Such analysis indicates the importance of ice dynamics in understanding future sea level change.

Focused research on ice dynamics is underway to improve the ability of climate models to address the scale and dynamics of change to glaciers, ice sheets, and ice caps (e.g., Price et al., 2011; Shepherd et al., 2012; Winkelman et al., 2012; Bassis and Jacobs, 2013; Little et al., 2013). Improved modeling will take time to be developed and tested and new models are not expected to be available for several years.

A.4.3. Semi-Empirical Method

The semi-empirical method for projecting sea-level rise is based on developing a relationship between sea level and some factor (a proxy) –often temperature or radiative forcing– and using this relationship to project changes to sea level. An important aspect of the proxy is that there be fairly high confidence in models of its future changes; a key assumption that is made by this method is that the historic relationship between sea level and the proxy will continue into the future. One of the first projections of this kind was based on the historic relationship between global temperature changes and sea level changes (Rahmstorf, 2007). This semi-empirical approach received widespread recognition with the publication of sea-level rise projections by Rahmstorf (2007). These projections looked at the temperature projections for two of the IPCC emission scenarios that span the likely future conditions within the IPCC framework -- B1, an optimistic, low-GHG emission future and A1FI, a more "business-as-usual" fossil fuel intensive future (See Box on Emissions Scenarios, below).[31] The 2007 projections of sea-level rise were used in the California 2009 Climate Change Scenarios Assessment (Cayan, 2009).

Since the initial semi-empirical projections for future sea-level rise (Rahmstorf, 2007), other researchers have published different projections based on the IPCC scenarios, using different data sets or best-fit relationships.[32] Notably, Vermeer and Rahmstorf (2009) prepared a more detailed methodology that includes both short-term responses and longer-term responses between

[31] When the IPCC began examining climate change, the available models were using a broad range of inputs. In an attempt to evaluate the different model outputs based on the different model characteristics, rather than the inputs, the IPCC developed a number of standard GHG emission scenarios. These scenarios are described in IPCC 1990 Response Strategies Working Group III. In general, the B1 scenario projects the lowest temperature and sea level increases and the A1FI projects the highest increases (IPCC 1990).

[32] Semi-empirical projections of sea-level rise through relationships between water level and radiative forcing such as those from Grinsted et al., 2009, Jevrejeva et al., 2010, Katsman et al. 2011, Rahmstorf et al., 2012, Meehl et al., 2012, Schaeffer et al., 2012 and Zecca & Chiari, 2012 have shown general agreement with the projections by Vermeer and Rahmstorf (2009). The Grinsted et al. projections have a wider range than those from Vermeer and Rahmstorf, while the Jevrejeva et al., projections are slightly lower. All semi-empirical methods project that sea level in 2100 is likely to be much higher than linear projections of historic trends and the projections from the 2007 IPCC.

sea-level rise and temperature. These 2009 projections of sea-level rise were used in the 2010 OPC Interim Guidance on Sea-Level Rise (OPC, 2010) and the California 2012 Vulnerability and Assessment Report (Cayan, 2012).

There are also several new semi-empirical sea-level rise projections based on scenarios other than those developed by the IPCC. For instance, Katsman et al. (2011) use a "hybrid" approach that is based on the one of the newer radiative forcing scenarios and empirical relationships between temperature change and sea level. Future projections were then modified to include contributions from the melting of major ice sheets based on "expert judgment". This yields what they call "high end" SLR projections for 2100 and 2200 under several emissions scenarios.

Zecca and Chiari (2012) produced semi-empirical sea-level rise projections based on their own "fossil fuel exhaustion" scenarios (different scenarios of when fossil fuel resources would be economically exhausted). Though based on a different set of assumptions about human behavior/choices, in terms of global temperature and radiative forcing, the scenarios do not differ greatly from the IPCC scenarios. The results are identified as being "lower bound" sea-level rise projections for high, medium, low fuel use scenarios, and "mitigation" (extreme and immediate action to replace fossil fuel use) scenarios. The report then provides projections for the 2000-2200 time period.

Figure 8 provides a visual summary of several of the more commonly cited projections of future global sea-level rise. The following box provides descriptions of the assumptions used in each of the IPCC AR4 (2007) scenarios.

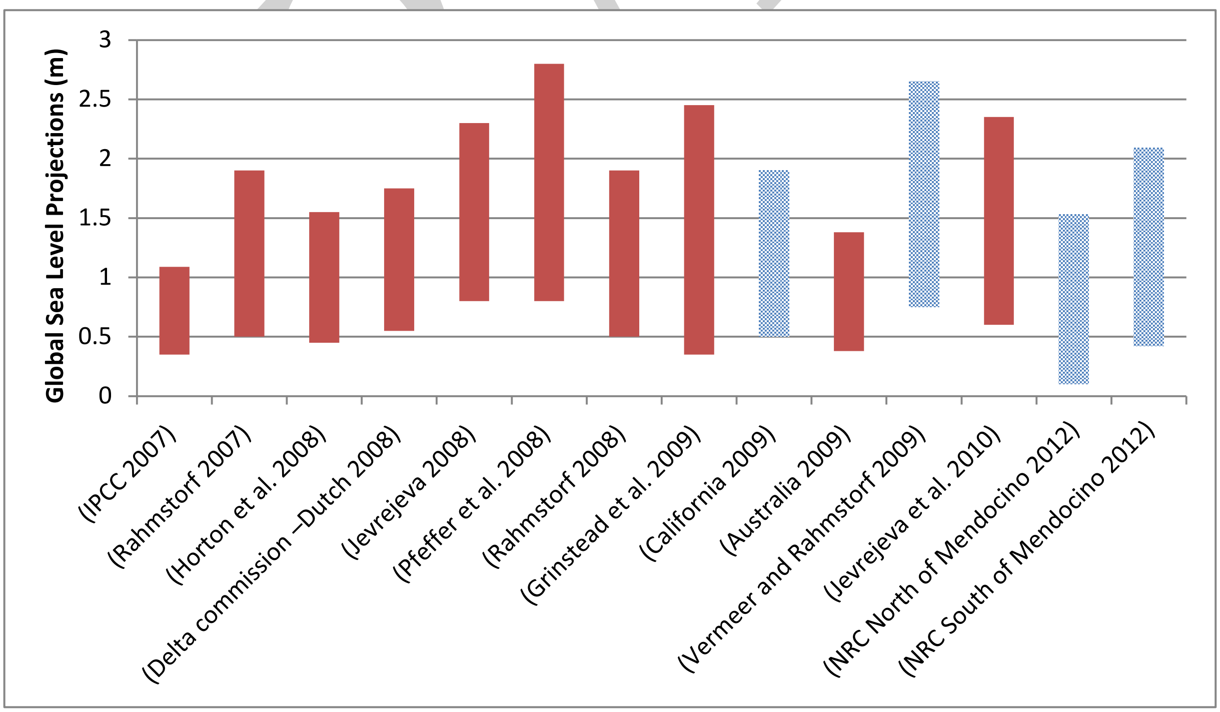

Figure 8. Various 2100 Global Sea-Level Rise Projections. Graphic summary of the range of average global sea-level rise (SLR) projections by end of century (2090–2100) from the peer-

reviewed literature) as compared to the recent National Research Council report for California, Oregon and Washington. The blue patterned boxes indicate projections for California. Ranges are based on the IPCC scenarios, with the low range represented by the B1 scenario (moderate growth and reliance in the future on technological innovation and low use of fossil fuels) and the high part of the range represented by the A1FI scenario (high growth and reliance in the future on fossil fuels). Details on the methods used and assumptions are in the original references.

The Emissions Scenarios of the Special Report on Emissions Scenarios (SRES)

A1. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system.

The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies).

A2. The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

B1. The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

B2. The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the A1 and B1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

(SOURCE: IPCC Special Report on Emissions Scenarios)

A.5. Recent Projections of Sea-Level Rise and Best Available Science on Sea Level

A.5.1. National Projections of Sea-Level Rise

Nationwide, the current best available science on sea-level rise projections is the Global Sea Level Rise Scenarios Report for the United States National Climate Assessment (NOAA, 2012). The report provides a set of four scenarios of future global sea-level rise, as well as a synthesis of the scientific literature on global sea-level rise. The NOAA Climate Program Office produced the report in collaboration with twelve contributing authors.[33] The report includes the following description of the four scenarios:

- **Low scenario:** The lowest sea level change scenario (8 inch rise) is based on historic rates of observed sea level change.
- **Intermediate-low scenario:** The intermediate-low scenario (1.6 feet) is based on projected ocean warming.
- **Intermediate- high scenario:** The intermediate-high scenario (3.9 feet) is based on projected ocean warming and recent ice sheet loss.
- **High scenario:** The highest sea level change scenario (6.6 feet) reflects ocean warming and the maximum plausible contribution of ice sheet loss and glacial melting. This highest scenario should be considered in situations where there is little tolerance for risk (NOAA, 2012).

The NOAA 2012 report provides steps for planners and local officials to modify these scenarios to account for local conditions. These steps are intended for areas where local sea-level rise projections have not been developed. For California, the NRC report (below) provides scenarios that have been refined for use at the local level, and the Coastal Commission, along with the State of California Sea Level Rise Guidance, recommends using the NRC projections rather than the global scenarios.

A.5.2. California-Specific Projections of Sea-Level Rise and Best Available Science

The National Research Council (NRC) Committee on Sea-Level Rise in California, Oregon and Washington (NRC Committee) recently released a report on regional sea-level rise trends and projections of future sea level change for California, Oregon and Washington. This report provides a broad examination of sea level for the California coast and currently represents the best available science on the topic. The NRC Committee investigated both the global and regional sea level projections, taking a different track than earlier efforts to develop sea-level rise projections both globally and for the California coast. The NRC Committee started with several of the basic scenarios that have been the foundation of the IPCC climate projections and the

[33] Authors include NOAA, NASA, the U.S. Geologic Survey, the Scripps Institution of Oceanography, the U.S. Department of Defense, the U.S. Army Corps of Engineers, Columbia University, the University of Maryland, the University of Florida, and the South Florida Water Management District.

earlier climate projections for California. They combined projections of steric changes (thermal expansion or contraction) with changes in the amount of ocean water due to melting of land-based ice on Greenland and Antarctica, as well as contributions from other land-based glaciers and ice caps. Table 5 shows the NRC projections for *global* sea-level rise.

Table 5. Recent Global Sea-Level Rise Projections for 2000 to 2100

Time Period	NRC Report, 2012 (Metric)		NRC Report, 2012 (English)	
	Average	Range	Average	Range
2000 – 2030	13.5 ± 1.8 cm	8.3 – 23.2 cm	5.3 ± 0.7 inch	3.3 – 9.1 inch
2000 – 2050	28 ± 3.2 cm	17.6 – 48.2 cm	11 ± 1.3 inch	6.9 – 19.0 inch
2000 – 2100	82.7 ± 10.6 cm	50.3 – 140.2 cm	32.6 ± 4.2 inch	19.8 – 55.2 inch

Source: NRC, 2012

After developing the global sea-level rise projections, the NRC Committee modified the global projections based on the influence of polar ice and regional changes in uplift and subsidence to create sea-level rise projections for California specifically. The NRC Committee identified distinctly different land level changes north and south of Cape Mendocino. The area north of Cape Mendocino is experiencing significant uplift of about 1.5 to 3 mm/yr (0.059 to 0.118 inches/yr) that the Committee attributed to plate movement along the Cascadia Subduction Zone (NRC, 2012, p. 93). In contrast, the coast south of Cape Mendocino is dropping at an average rate of about 1 mm/yr (0.039 inches/yr) (NRC, 2012, p. 93). The measurements of land subsidence south of Cape Mendocino vary widely, from -3.7 mm/yr to +0.6 mm/yr (-0.146 inches/yr to + 0.024 inches/yr) (NRC, 2012, p. 93), with slightly greater subsidence in southern California than in Central California.[34] The NRC Committee noted that the uplift being experienced along the Cascadia Subduction Zone may reverse during a fault rupture or earthquake of magnitude 8.0 or greater along the Cascadia Subduction Zone. The NRC report notes that during a large earthquake (magnitude 8 or greater), coastal areas could experience sudden vertical land motion, with uplift in some locations and subsidence as much as 6.6 feet (2 meters) in other locations (NRC, 2012). Despite the rapid reversibility of much of the coastal uplift north of Cape Mendocino, the NRC Report provided projections of regional sea level through 2100 that incorporate land uplift. Table 6 shows the regional projections of sea-level rise from the NRC Report.

[34] Personal Communication to staff from Anne Linn, NRC Study Director (August 1, 2012)

Table 6. California Sea-Level Rise Projections for 2000 to 2100

Time Period	NRC Report 2012	
	North of Cape Mendocino[35]	South of Cape Mendocino
2000 – 2030	-4 – +23 cm (1.6 – +9.0 inch)	4 – 30 cm (1.6 – 12 inch)
2000 – 2050	-3 – + 48 cm (-1.0 – +19.0 inch)	12 – 61cm (5 – 24 inch)
2000 - 2100	+10 – +143 cm (+4 – +56 inch)	42 – 167 cm (16.5 – 66 inch)

Source: NRC, 2012.

The NRC report also provides sea-level rise projections for four individual coastal communities that have long-term tide gauge records, including San Francisco and Los Angeles. These projections match the regional projections for south of Cape Mendocino to within a few millimeters, demonstrating that the regional projections track closely with more localized projections. The NRC report provides no information about the appropriate coastal section that might be included with either the San Francisco or Los Angeles projections. Due to the lack of direction about how to use the localized projections and their close fit with the regional values, the NRC scientists recommend using the regional values, with the exception of parts of Humboldt Bay and the Eel River estuary, unless the area in question is very close to either San Francisco or Los Angeles.

A.5.3 Findings from 2012 NRC Report on Natural Shoreline Responses to Sea-Level Rise

Rising sea level will accelerate many of the flooding and erosion conditions that are already putting coastal development and infrastructure at risk. Some of the key findings about impacts to natural shorelines throughout California from the NRC report include:

- **Bluffs and cliffs:** Sea-level rise will lead to an increase in bluff erosion and bluff retreat because more wave energy will be available to erode cliffs and bluffs. Waves will break closer to the coastline and will reach the base of the cliff or bluff more frequently, increasing the rate of retreat. Current responses such as armoring bluffs will be less effective as overtopping occurs more frequently.

- **Beaches:** Sea-level rise will cause landward migration or retreat of beaches over the long term. Beaches with seawalls or other barriers will not be able to migrate landward and the sandy beach areas will gradually become inundated.

- **Coastal dunes:** Sea-level rise will cause dunes to retreat quickly.

[35] With the exception of parts of Humboldt Bay and the Eel River Estuary which are experiencing subsidence and therefore a higher rate of sea-level rise than projected for the region.

- **Changing retreat rate:** The report finds that extrapolation of current erosion rates until 2030 is a reasonable approach. Beyond 2030, the report recommends that an unspecified "safety factor" should be added to existing trends to accommodate future sea-level rise and potential increases in storm wave heights.

- **Estuaries and tidal marshes:** Sea-level rise may affect the tidal dynamics within the estuary, including the tidal range. The transition from intertidal flats to marshes is especially sensitive to changes in sea level, depending on salinity and inundation tolerance limits of vegetation. Marshes will migrate inland if land is available and the marsh is able to build in elevation at a rate that keeps pace with sea-level rise. Estuaries and marshes that have adequate space to migrate can buffer the impacts of sea-level rise to built environments.

- **Coastal sediment supplies:** Supplies of sediment to the coast will be important for survival of wetlands and tidal marshes, and to a lesser extent, of beaches during rising sea level. Through 2050, frequent storms that promote sediment deposition could allow marshes to survive; by 2100 only areas of high sediment supplies may support viable marsh habitat if the higher range of sea level is experienced. In northern California, water management practices will also be important for long-term marsh survival.

APPENDIX B. DEVELOPING LOCAL HAZARD CONDITIONS BASED ON REGIONAL OR LOCAL SEA-LEVEL RISE USING THE NRC 2012 REPORT[36]

Determining local hazard conditions is one of the first steps in sea-level rise planning efforts. Because sea-level rise varies locally, this analysis must be performed on a site-by-site basis, and obtaining data or conducting research at the correct geographical scale is something project applicants and planners should prioritize. The 2012 NRC Report is the best available science on California's regional sea-level rise, and it should be used when sea-level rise projections are needed.

Much of the research by the IPCC and others, and even the material in the 2012 NRC Report, has focused on global and regional changes to mean sea level. However, the coast is formed and changed by local water and land conditions. Tide range influences where beaches, wetlands and estuaries will establish; waves and currents are majors drivers of shoreline change; storms and storm waves are often the major factors causing damage to coastal development. It is local conditions that influence beach accretion and erosion, storm damage, bluff retreat and wetland function.

Local water levels along the coast are affected by local land uplift or subsidence, tides, waves, storm waves, atmospheric forcing, surge, basin-wide oscillations, and tsunamis. Some of these factors, such as tides and waves, are ever-present and result in ever-changing shifts in the local water level. Others, such as storms, tsunamis, or co-seismic uplift or subsidence, are episodic but can have an important influence on water level when they occur. The following section discusses these factors in the context of sea-level rise and how they are incorporated into planning and project analysis.

In most hazard situations, high water will be the main project or planning concern. For wetlands, low and high tides will be of concern and, in some special situations, such as for intake structures, low water might be the main concern. In some situations where low water is the concern, current low water is likely to be the low water planning condition and there may be no need to factor future sea-level rise into those project or planning situations. The following Text Box identifies some of the key situations or indicators that may be important for coastal managers and applicants to consider sea-level rise during project review.

[36] This guidance provides specific direction for using the materials from the 2012 NRC Report. As the best available science for sea-level rise changes, Commission staff will assess whether revisions to this guidance will be needed. Until this is revised, readers should use their best judgment in applying this guidance for other reports. For example, information is provided for developing sea-level rise projections for years other than 2030, 2050, or 2100. If the next report provides projections for different years than 2030, 2050, or 2100, the new projection years can be substituted for the NRC years. If new projections are found to improve the information from the NRC report, the formula for interpolation of the NRC projections should not be used.

General Situations when Sea-Level Rise Analysis Should be Considered Project or planning site is: • Currently in or adjacent to an identified floodplain • Currently or has been exposed to flooding from waves • Currently in a location protected from flooding by constructed dikes, levees, bulkheads, etc. • On or close to a beach, estuary, lagoon, or wetland • On a coastal bluff with historic evidence of erosion • Reliant upon shallow wells for water supply

For situations where future sea level conditions will be important, the following steps are provided as guidance for determining local hazards. Figure 9 shows the general progression for going from global sea level projections to the possible consequences or impacts that can result from local water levels.

1. **Determine appropriate planning horizon or expected project life.** Determine the appropriate planning horizon or expected project life (which is often provided in the LCP). For many planning efforts, more than one planning horizon may be needed.

2. **Determine regional sea level projections for planning horizon or expected project life.** Select an appropriate regional sea-level rise projection based on the planning horizon or expected project life. For scenario-based planning and project analysis, more than one sea-level rise projection should be used.

3. **Modify regional sea-level rise projections for local vertical land motion:** Modify the regional sea-level rise projection to account for local vertical land motion, if appropriate. In locations with a large discrepancy between the recorded sea level trend and the regional projections (such as Humboldt Bay), modifications of the regional sea-level rise projections will be necessary. In most situations, the values from the NRC Report can be used without modification.

4. **Project tidal elevations and future inundation:** Project future tidal elevations (mean higher high, mean lower low, etc.), based on historic tidal records and the appropriate NRC (2012) sea-level rise projection.

5. **Determine water level changes from surge, El Niños, PDOs, etc.:** Determine projected water level changes from storm surge, atmospheric pressure, the El Niño/Southern Oscillation, the Pacific Decadal Oscillation or other basin-wide phenomena.

6. **Estimate beach, bluff, and dune change from erosion:** Estimate likely future beach erosion and beach scour, or bluff erosion, if bluffs are present, for appropriate planning horizon or expected project life, including if possible, the changes in erosion due to sea-level rise.

7. **Determine potential flooding, wave impacts, and wave runup:** Determine projected wave impacts and wave runup from a 100-year storm event, for planning horizons or expected project life, based on high tide and other water level changes, future beach and bluff erosion and future beach scour.

8. **Examine potential flooding from extreme events:** Examine possible impacts from extreme events, such as storms with return intervals greater than 100 years, tsunamis, etc.

9. **Repeat as necessary:** Repeat for each planning horizon or sea-level rise scenario.

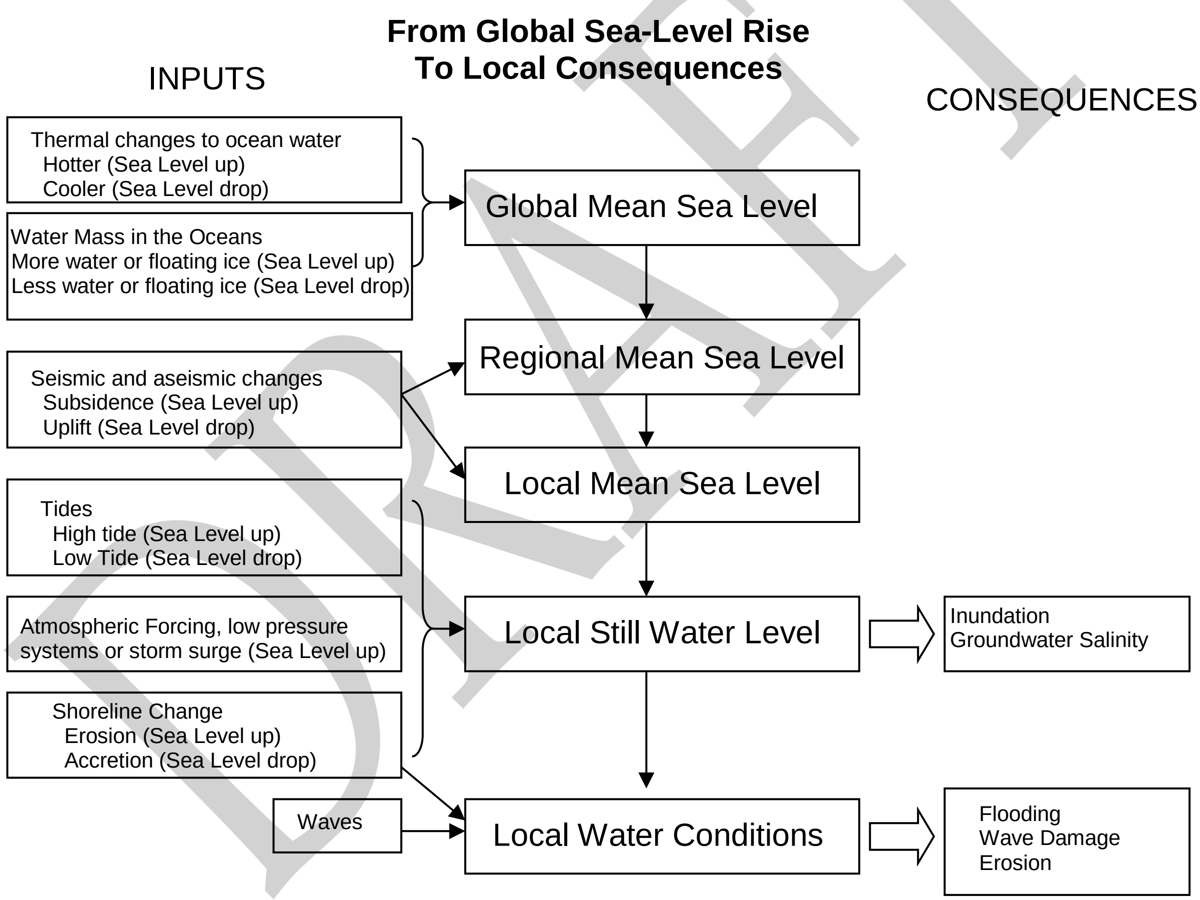

Figure 9. General process for changing global sea-level rise for local conditions.

Step 1 – Determine Appropriate Planning Horizon or Expected Project Life

The first step in a sea-level rise analysis is to determine the appropriate planning horizon or expected life of the project. The longer the life of a project or planning horizon, the greater the amount of sea-level rise the project or planning area will experience. Also, since future sea level is not expected to be linear, the amount of sea-level rise that can be expected to occur over some length of time will increase with a later starting time. For example, a project built today will experience less sea-level rise over a 50-year lifetime (about 24 inches or 61 centimeters using the higher projections for south of Cape Mendocino) than the same project if it were built in the year 2050 (about 40 inches or 101 centimeters, using the higher projections for south of Cape Mendocino). Thus, it is important to understand the projected life of a structure and the planning horizon before starting an analysis for sea-level rise concerns.

Local governments should select their planning horizons to evaluate a broad range of planning concerns. Planning horizons might address the 20-year time period for general plan updates to the long-range planning necessary for infrastructure and new development. At the project level, the LCP can often provide insight into the time period that should be considered for the expected project life. At present, most LCPs provide only a single standard for the expected life of structure or development, normally 50, 75, or 100 years. Future LCPs and LCPAs may find it useful to provide greater guidance on expected project life, with differentiations among major development or use classifications.

Outcome from Step 1: *Step 1 provides an identification of the years and time periods that will be used in analysis of the project or development of a plan*.

Step 2 – Determine Regional Sea Level Projections for Planning Horizon or Expected Project Life

The second step in an analysis of sea-level rise is to determine the regional sea-level rise projections that are appropriate for the proposed project or planning effort. At present, the 2012 NRC report provides the best available science for regional sea-level rise projections. However, these projections are provided as changes in sea level from the year 2000 to 2030, 2050, and 2100. If the planning horizon or expected project life is at or very close to these years, the projections can be used as given. In many cases, these projections will need to be modified to obtain projections for the time periods of interest. There are several modifications that may be appropriate:

- Developing sea-level rise projections for years other than 2030, 2050 or 2100.
- Developing sea-level rise projections for planning or projects with start times other than the year 2000.
- Developing sea-level rise projections for planning or projects with an anticipated life beyond the year 2100.

Guidance for all three situations is provided below.

Projection of sea-level rise for years other than 2030, 2050, and 2100

For sea-level rise projections for years within a few years of those used in the NRC projections, the 2030, 2050, and 2100 projections can be used. However, for years that are not close to these years, sea-level rise projections should be interpolated from the projections. Two methods are recommended for establishing a projection value for a specific year: (1) conduct a linear interpolation[37], or (2) use the "best fit" equations that are provided below. At this time, both are acceptable.

1. Linear Interpolation: One method for establishing a sea-level rise projection for a specific year is linear interpolation between the two known or given projections. The most immediate time periods before and after the desired time period should be used. For example, for a proposed project south of Cape Mendocino with an expected life till 2075, the upper range for the sea-level rise projections closest to this time period are 2.0 feet (61cm) for 2050 and 5.48 feet (167 cm) for 2100.

SLR(2075) = SLR(2050) + ((SLR2100 – SLR2050) x (2075 - 2050/(2100 – 2050))
= 2.0' + ((5.48' – 2.0')(2075 – 2050)/(2100 – 2050)
= 2.0' + ((3.48)(25)/50) = 3.74' (114 cm)

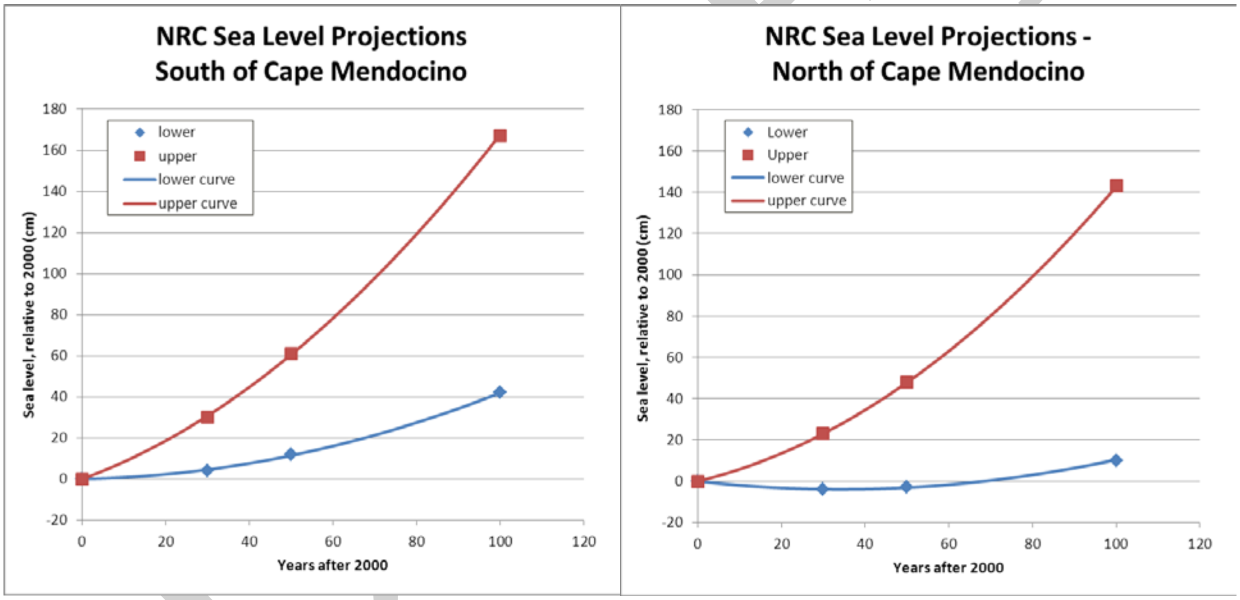

Figure 10. Sea-level Rise Projections, North and South of Cape Mendocino (from NRC Report)

2. Use Equation: A second option is to use one of the following quadratic equations that represent the "best fit" for each of the above sea-level rise curves. These equations can be used to project sea-level rise for years other than 2030, 2050, and 2100. These equations provide sea-level rise in centimeters. If English units are desired, the projections will need to be converted using 1 cm = 0.0328 feet, or 1 cm = 0.394 inches.

[37] Linear interpolation is a method for filling in gaps in data or information that assumes that two known data points that bound the unknown point can be connected with a straight line. The missing information is estimated through reference to this line. The example in the text provides an example of the mathematical steps for linear interpolation.

Equations for Sea-Level Rise Projections, based on values from the NRC Report (NRC 2012)

North of Cape Mendocino

- Upper Range -- Sea Level Change (cm) = $0.0094t^2 + 0.4868t$ (Equation B-1)
- Lower Range – Sea Level Change (cm) = $0.0033t^2 - 0.2257t$ (Equation B-2)

South of Cape Mendocino

- Upper Range – Sea Level Change (cm) = $0.0093t^2 + 0.7457t$ (Equation B-3)
- Lower Range Sea Level Change (cm) = $0.0038t^2 + 0.039t$ (Equation B-4)

Where "t" is the number of years after 2000

For example, if the proposed project were south of Cape Mendocino, with an expected life of 75 years, use Equation B-3, with t = 75.

$$\text{Sea Level Change (cm)} = 0.0093 \times (75)^2 + (0.7457 \times 75) = 52 + 56 = 108 \text{ cm}$$

The sea level change projected using the equation is slightly less than that projected by linear interpolation because the NRC's sea level curves, shown in Figure 10, are concave upward (sea-level rise is expected to accelerate over the 21st century). A line between any two points on the curve will always be slightly higher than the curve itself.

As noted previously, either method is acceptable for estimating sea-level rise for a year that has not been provided in the NRC Report.

Ranges of sea-level rise projections that do not start at the year 2000

The NRC sea-level rise projections use the year 2000 as the base year. Since there has been little, if any, measureable rise in sea level since 2000 for most locations in California (Bromirski et al., 2011; NOAA Tides and Currents, 2013), there is little reason or justification for adjusting sea-level rise projections from 2000 to a more current start date. All of the latent sea-level rise might occur quickly, providing sea level conditions consistent with the future projections. Thus, when the needed sea level value is a projection of the future sea level that will be experienced by a proposed project for a proposed planning situation, there is no need to adjust the 2012 NRC projections for a different project starting year.

If the needed sea-level rise value is the range of sea level that might be experienced over a future time period, as might be used for planning a wetland restoration project, then adjustments to the starting point for sea-level rise projections may be necessary. Given the recent lack of sea level change in California, it is suggested that such planning or design efforts not do any adjustments to the sea-level rise projections for start dates prior to about 2015 or 2020. When the range of sea level exposure is needed for a future planning scenario, this sea level range can be developed by interpolating the sea level projections for the starting and ending years, and obtaining the difference in sea level by subtracting these two. For example, if a restoration project will be designed to take into account the sea-level rise that will occur from 2040 to 2060, use Equations

B-1, B-2, B-3 or B-4 to get SLR(t1) and SLR(t2) and subtract SLR(T- 40 years) from SLR(t= 60 years) to get the range of sea-level rise from 2040 to 2060.

Sea-level rise projections beyond 2100

Sea-level rise is expected to continue well past the year 2100, despite the termination of most projections at that year.[38] The uncertainty associated with any projections for sea level grows significantly as the time period increases. There are large uncertainties in projections for sea-level rise in the 2100 time period. However, long-term planning and projects requiring long lead times or large capital expenditures need to consider conditions that might occur in the next 100 or more years.

At this time, there are no studies that specifically address projections of sea-level rise for California beyond the year 2100. The NRC projections stop at 2100 and provide no guidance for extrapolation of the range of sea-level rise projections past that time. The equations provided above, while most appropriate for interpolation up to 2100, can be used to extrapolate sea-level rise for a few years beyond 2100. For projections beyond about 2105 or 2110, alternative methods should be considered for developing sea-level rise projections.

1. Use the NRC projections for 2050 and 2100 to develop a linear trend beyond 2100.
2. Use sea-level rise rates that have been developed in recent years, some of which are provided in Table 7.
3. Interpolate between the NRC projections, and one of the reports that provides projections of global sea-level rise for 2200 or 2300 (some of which are listed in Table 8).

None of these options will provide sea-level rise projections that have a confidence similar to the NRC projections. Eventually, there may be regionally appropriate projections for sea level into the 22nd and 23rd centuries. Until then, some assumptions may need to be used for analysis that goes into these time periods. It is clear that sea level will continue to rise past 2100, and any effort to look beyond the year 2100 will be better than using projections of sea-level rise for 2100 as the upper limit of what might happen beyond that time. Nonetheless, it is critical that long-range planning efforts and projects with long design lives include provisions to revisit SLR hazards periodically, and to make adjustments as new science becomes available.

[38] For example, a recent study by Levermann et al. (2013) suggests that, due to slow-acting ice sheet processes and climate feedbacks, global warming of just 2 ºC (at the low end of current projections for the 21st century) would "commit" the planet to between 2.6 – 7.5 meters of sea-level rise over the next 2,000 years.

Table 7. Range of Global Sea-level Rise (from Nichols et al., 2011)

Sea-level rise Feet/century (Meters/century)	**Methodological Approach**	**Source**
1.6 – 4.6 (0.5 – 1.4)	Semi-empirical projection[b]	Rahmstorf 2007
2.6 - 7.9 (0.8 – 2.4)[a]	Paleo-climate analogue	Rohling et al.2008
1.8 – 3.6 (0.55 – 1.10)	Synthesis[b]	Vellinga et al. 2008
2.6 – 6.6 (0.8 – 2.0)	Physical constraints analysis[b]	Pfeffer et al. 2008
1.8 – 3.0 (0.56 – 0.92)[a]	Paleo-climate analogue	Kopp et al. 2009
2.5 – 6.2 (0.75 – 1.90)	Semi-empirical projection[b]	Vermeer & Rahmstorf 2009
2.4 – 5.2 (0.72 – 1.60)[c]	Semi-empirical projection[b]	Grinsted et al. 2009

[a] Higher rates are possible for shorter periods
[b] For the 21st century
[c] For the best paleo-temperature record.

Table 8. Projections of Global Sea-level rise Beyond 2100

Projection Scenario[a]	Sea-level rise for 2300, referenced to 2000 (Schaeffer et al., 2012) ft (m)	2300 Sea-level rise rate (Schaeffer et al., 2012) inches/yr (mm/yr)	Sea-level rise for 2500, referenced to 2000 (Jevrejeva et al., 2012) ft (m)
RCP4.5	7.0 – 17.3 (2.12 – 5.27)	0.24 – 0.74 (6 - 20)	2.4 – 14.1 (0.72 – 4.3)
RCP3PD	3.9 – 10 1 (1.18 – 3.09)	0.04 – 0.35 (1 - 9)	0.4 – 5.7 (0.13 – 1.74)
RCP6			3.4 – 19.0 (1.03 – 5.79)
RCP8.5			7.4 – 37.8(2.26 – 11.51)
Stab 2°C	5.1 – 13.2 (1.56 – 4.01)	0.16 – 0.55 (4 – 14)	
Merge400	2.8 – 7.7 (0.86 – 2.36)	-0.08 – 0.12 (-2 – 3)	
Zero 2016	2.5 – 6.8 (0.76 – 2.08)	0.04 – 0.24 (1 – 6)	

[a] See referenced reports for details on projection scenarios.

Outcome from Step 2: *Step 2 provides a regional sea-level rise projection that can be used to for project analysis or development of a plan.*

Step 3 – Modifying Regional Sea-Level Rise Projections for Local Vertical Land Motion

NOTE: This step is necessary only for project analysis or planning efforts in the vicinity of Humboldt Bay and the Eel River estuary. For all other areas, this step can be skipped.

Changes in land level, either from uplift or subsidence, will affect the sea level measured at that location. Relative sea level, also known as local sea level, is the term used to describe changes to locally measured sea level from land uplift or subsidence (i.e. sea-level rise relative to land change). For land that is subsiding while sea level is rising, the rates are additive such that regional sea-level rise will be the sum of global sea-level rise plus land subsidence. If the land is undergoing uplift, the uplift will cancel out some or all sea-level rise, and regional sea level will be global sea-level rise minus land uplift.

Relative Sea Level Change Rate = Sea-level rise Rate + Land Subsidence Rate

Or

Relative Sea Level Change Rate = Sea-level rise Rate – Land Uplift Rate

The NRC Report has adjusted regional sea level projections for the large-scale uplift and subsidence that has been observed along the coast. However, the NRC projections have not taken into account the local variations in vertical land motion that occur. However, in guidance developed for the OPC, a three-member subcommittee of the OPC Science Advisory Team (OPC-SAT) advised using the NRC projections, without modification, for all California locations except between Humboldt Bay and Crescent City. The OPC-SAT subcommittee stated, "We do not believe that there is enough certainty in the sea-level rise projections nor is there a strong scientific rationale for specifying specific sea-level rise values at individual locations along California's coastline." (OPC, 2013, pg. 10)

Site-specific modifications to the NRC projections will be needed for the Humboldt Bay and Eel River estuary area, where the tide gauge records show a very different sea-level rise trend than what is projected for the North of Cape Mendocino region. The OPC-SAT Subcommittee advises that for the northern California coast, sea-level rise projections be developed from the recorded tide gauge rates at Humboldt and Crescent City "augmented by any future acceleration in rates of sea-level rise … for the areas closest to these gages, with intermediate values for the areas between them" (OPC 2013 pg. 11). Table 9 shows the historic sea level trend, based on tide gauge records for the North Spit of Humboldt Bay and for Crescent City that can be used for local sea-level rise adjustments for the area north of Cape Mendocino.

Table 9. Sea Level Trends for Humboldt Bay, CA and Crescent City, CA

Location	Period of Record	Sea Level Trend (ft/century)	Sea Level Trend (mm/yr)
Humboldt Bay	1977 - 2013	1.36 +/- 0.38	+4.14 +/- 1.15
Crescent City	1933 - 2013	-0.27 +/- 0.11	-0.81 +/- 0.33

Source: NOAA Tides and Currents, 2013, "Updated Mean Sea Level Trends". Retrieved July 2, 2013 from http://tidesandcurrents.noaa.gov/sltrends/sltrends_states.shtml?region=ca.

The OPC-SAT Subcommittee recommended using the NRC sea-level rise projections for most locations south of Cape Mendocino, without local adjustments for vertical land motion. This recommendation should be given serious consideration. If a local government or project applicant should decide to include local vertical land motion, for a particular reason, the local land changes should replace the regional projections of vertical land change assumed by the NRC report (from Table 5.3 of the NRC Report and reproduced in Table 10). If local trends are applied to the regional projections, the inclusion of local uplift or subsidence will compound the regional land changes already included in the NRC Report.

Table 10. Regional Vertical Land Motions used in NRC Regional Sea Level Projections

	North of Cape Mendocino				South of Cape Mendocino			
	Centimeters		Inches		Centimeters		Inches	
	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range
2000 – 2030	-3.0	-7.5 - +1.5	-1.1	-3.0 - + 0.6	4.5	0.6 – 8.4	1.8	0.2 – 3.3
2000 – 2050	-5.0	-12.5 - + 2.5	-2.0	-4.9 - +1.0	7.5	1.0 – 14.0	3.0	0.4 – 5.5
2000 – 2100	-10.0	25.0 - + 5.0	-4.0	-9.8 - +2.0	15.0	2.0 – 28.0	5.9	0.8 – 11.0

NOTE: Negative values show uplift and positive values show subsidence. If no sign is used, values are positive for subsidence.)

The NRC report provides some vertical land motion information to assist with modifying regional sea-level rise for local conditions. Appendix A of the NRC Report provides vertical land motions for eight California locations (Crescent City, San Francisco, Alameda, Port San Luis, Santa Monica, Los Angeles, La Jolla and San Diego). In addition, Appendix D of the NRC Report, “Long-term Tide Gage Stability from Land Leveling” provides a discussion on tide gauge observations, with long-term vertical land motion for Crescent City, San Francisco, Port San Luis, Los Angeles, and San Diego.

Local vertical land motion can be influenced by many of the factors. Each factor may alter vertical land motion differently and detailed projections of future vertical land motion may need to be developed from the trends for each of the individual components. Seismic activity can often influence vertical land motion and vertical land motion trends during times of high seismic activity may be very different from those recorded during periods of low seismic activity. Groundwater pumping and fluid extraction can have a major influence on vertical land motions. But, effects from fluid extraction will be localized and vertical land motion measurements close to the extraction areas will be needed to quantify local vertical land motion. Historic trends in vertical land motion for one location may not be appropriate for another location, even one that is only 5 or 10 miles away. Several programs have been established to better understand vertical land motion, but they have been in operation for at most a few decades, and long-term projections of vertical land motion are difficult to develop. Projections of local land motion introduce another layer of uncertainty into sea-level rise projections. When local vertical land motions are used to modify the regional sea-level rise projections, there should be at least one scenario that examines the consequences from the unmodified regional sea-level rise range.

Outcome of Step 3: *Step 3 provides a locally modified sea-level rise projection that can be used for project analysis or development of a plan.*

Step 4 – Project Tidal Range and Future Inundation

One of the most basic examinations of changing sea level conditions has been to determine the new intersection of mean sea level or other tidal levels with the shoreline. This has been called the "bathtub" analysis since it looks only at the expansion of areas that will be inundated (i.e. regularly submerged under water). The inundation level will move up in elevation and the zone of inundation will move inland, generally following the existing slope of the beach or shore. So the future inundation level can be approximated as the sum of the current water level plus future regional mean sea-level rise. The future inundation zone will be where this water level meets land.

Future Water Elevation = Current Water Elevation + Projected Sea-level rise

Future Water Location = Intersection of Elevation with Future Shore Location

For example, future sub-tidal levels would be the current subtidal limit plus projected regional mean sea-level rise. Future intertidal zones would be bounded by the current higher high tide level plus projected regional mean sea-level rise and lower low tide levels plus projected regional mean sea-level rise.[39] For some projects, such as wetland restoration, the identification of future inundation zones may be the only sea level analysis needed for project evaluation. If the shoreline is eroding, the location of this elevation would need to also incorporate the rate of erosion. So, not only will the intertidal zone move up in elevation, if the shoreline is expected to erode due to increased wave attack, the intertidal zone will be both higher than and inland of the current zone.

Inundation will extend to the location of the new inundation elevation. On beaches with a gradual slope, this can move the inundation location significantly inland, based on the slope (geometric conditions) of the beach. (This type analysis is often called the Bruun Rule). On a stable beach with a slope of 1:X (Vertical:Horizontal), every foot of vertical sea-level rise will move the inundation area horizontally X feet inland. For a typical 1:60 beach, every foot of sea level would move the inundation zone inland by 60 feet. If the beach is eroding, the loss due to inundation will add to the loss from erosion.

Figure 11 shows the influence of tides and sea-level rise on low-wave energy beaches. Table 11 provides some useful resources for inundation studies. For the open ocean coast, where waves are a dominant feature of a beach, the changes to the beach need to include waves, as discussed later in this section.

[39] Historic trends of high and low tide have changed differently than mean sea level (Flick et al. 2009). Based on historic trends, the changes to various tidal elements are likely to track closely with, but not identically with, changes to mean sea level. The future variability of changes to the tidal components, compared with changes to mean sea level will normally be within the uncertainty for sea-level rise projections and can be ignored for almost all situations. As this phenomenon of tidal change is better understood and can be modeled, it may be appropriate in the future to include the changes in tidal components into the analysis of inundation and various water level projections.

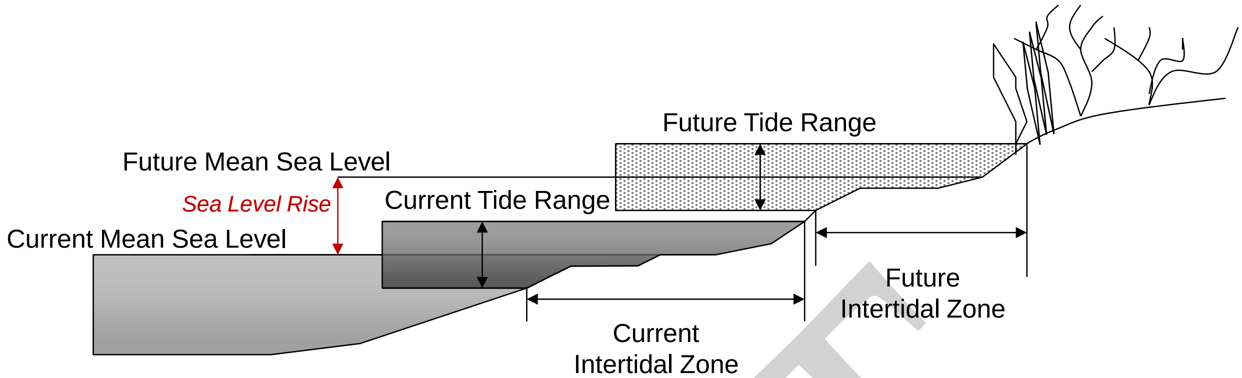

Figure 11. Sea-level rise and Changes to Tide Range and Intertidal Zone.

Table 11. General Resources for Inundation Studies

Resource	Specifics of Information	Source
Aerial Photographs	Useful for general information on shoreline trends Ortho-rectified photos can help quantify trends	California Coastal Records Project; www.californiacoastline.org Huntington Library Local Libraries
LIDAR	Fairly detailed topography Can provide GIS layers for current conditions Comparable with LIDAR data sets for temporal changes	NOAA Coastal Services Center - http://www.csc.noaa.gov/data/index.html
Topographic Maps	Often not at a scale to distinguish small changes in water levels	USGS Map Center - http://www.usgs.gov/pubprod/maps.html
NOAA Sea Level Rise Viewer	Useful to show changes in water level location if there are no changes in the land due to erosion.	NOAA's Digital Coast http://www.csc.noaa.gov/digitalcoast/tools/slrviewer
Tidal Data	Measured and predicted tidal components for locations along the open coast and in bays.	http://tidesandcurrents.noaa.gov/
Cal-Adapt – Exploring California's Climate	Shows coastal areas that may be threatened by flooding from a 1.4 meter rise in sea level and a 100-year flood event. Maps do not now include any influence of beach or dune erosion or existing protective structures.	http://cal-adapt.org/sealevel/

Outcome from Step 4: *Step 4 provides information on the projected changes to the tidal range and future zones of inundation. For locations without any influence from erosion, storm surge, or wave energy, the identification of new inundation areas may be sufficient for project analysis and planning efforts. This projected new inundation area may also be useful for anticipating the likely migration of wetlands and low-energy water areas or as input for analysis of changes groundwater salinity. For most open coast situations, this information will be used to inform further project analysis and planning that examines erosion, surge and storm conditions.*

Step 5 – Determine Water Level Changes from Surge, El Niños, PDO, etc.

Estimates of surge, El Niño and PDO water elevation changes are developed primarily from historic records. There are no state-wide resources for this information, although it may be included in one of the regional Coastal California Storm and Tide, Wave Studies prepared by the US Army Corps of Engineers. General guidance on water level changes that can be expected from surge and El Niños is provided in Table 12.

The remaining discussion provides general information on some of these phenomena. It is provided to acquaint readers to the main issues associated with each. Readers with a strong background in ocean-atmospheric conditions may want to skim or skip the rest of this section.

The Pacific Ocean is a complex system. Sea level in the Pacific Ocean is a response to multiple oceanic and atmospheric forcing phenomena, occurring with different intensities and at different temporal and spatial scales. Some phenomena may reinforce each other, while other may act in opposition, essentially canceling each other out. Scientists and researchers are attempting to identify the various signals from the multiple phenomena, but these are nascent sciences and there is still much we need to learn.

Regional water levels can be modified by surge as well as by high and low pressure systems. Surge is a short-term change in water elevation due to high wind, low atmospheric pressure, or both. It is most often associated with east coast and gulf coast hurricanes that can cause up to 15 or 20 feet (4 to 6 meters) or more of short-term water level rise over many miles of the coast. Along the west coast, storm surge is much smaller, and is rarely a coastal hazard, except in enclosed bays. In southern California it rarely exceeds one foot (0.3 meters) and in central California, it rarely exceeds 2 feet (0.6 meters). Surge becomes a concern because it is one of several cumulative factors that cause a temporary rise in sea level. Each rise may be small, but when they occur in combination or during high tides and with storms, they increase the threat of coastal flooding, wave impacts and erosion.

Two of the more recognized phenomena that affect water temperature in the Pacific are the El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). ENSO cycles, which occur on inter-annual timescales (approximately 2-7 yr), involve ocean-basin-spanning changes in sea surface temperature (SST) and the depth of the mixed layer in the Equatorial Pacific, but also drive changes in ocean conditions and atmospheric circulation at higher latitudes. El Niño events result in the transfer of warm surface waters into the normally cool eastern equatorial Pacific, resulting in elevated SST and water levels along much of the west coast of the Americas. El Niños also tend to increase the strength and frequency of winter low pressure systems in the North Pacific. These events can persist for months or years at a time, and strongly influence local and regional sea level. For example, the pulse of warm water from the large 1982-83 El Niño caused water levels along the California to be elevated by approximately 0.4 - 0.7 feet (0.12 – 0.21 m) for many months, with short-term water elevation peaks up to about 1 foot (0.3 m) (Flick, 1998). The opposite phase of ENSO, characterized by unusually cool SSTs and lower water elevations along the eastern Pacific margin, are called La Niña events. Between El Niños and La Niñas are periods of neutral SST and water elevation changes.

The PDO is an ENSO-like pattern of SST and atmospheric variability occurring over multiple decades. In contrast to ENSO, the PDO is more strongly expressed in the North Pacific than in the tropics. The positive or warm phase of the PDO is associated with unusually warm surface water along eastern North Pacific (the western US coast), while the negative or cool phase PDO is associated with colder than normal water. As with the ENSO effects, the warm phase PDO has tended to cause elevated sea levels in the eastern Pacific and along the California coast, while the cool phase of the PDO tends to lower sea level in this region.

The PDO has basin-wide influence. Elevated water levels in one part of the Pacific are often accompanied by lowered water levels elsewhere. The cool phase PDO can result in a drop of water level along the eastern Pacific (western US coast) and a rise in water level along the western Pacific. Recently, sea level along the western Pacific has been rising about three times faster than the global mean sea-level rise rate (Bromirski et al., 2011; Merrifield, 2011). This does not mean the eastern Pacific will experience sea-level rise that is three times faster than the global mean sea-level rise when there is the next shift in the PDO, but does show that the PDO can have a major influence on basin-wide and regional sea level.

The above discussion of El Niño and the PDO suggests that there are well-understood, readily predicted changes in sea level that result from these phenomena. However, it is important to note that El Niños have varying strengths and intensities, resulting in different sea changes from one event to the next. And, changes in regional mean sea level along the eastern Pacific have not always shown a strong connection to the PDO cycles. An apparent jump in regional mean sea level occurred after the mid-1970s shift to the warm phase of the PDO, yet the expected continued rise in sea level along the West Coast seems to have been suppressed by other forces. Tide gauge records for the Washington, Oregon and California coasts have shown no significant interannual rise in sea level from 1983 to 2011 (Cayan et al., 2008; NOAA Tides and Currents, 2013; Bromirski et al., 2011). Bromirski et al. (2011 & 2012) postulate that persistent alongshore winds have caused an extended period of offshore upwelling that has both drawn coastal waters offshore and replaced warm surface waters with cooler deep ocean water. Both of these factors cause a drop in sea level that may have cancelled out the sea rise that otherwise would be expected from a warm phase PDO signal.

Water level changes from surge, atmospheric forcing, El Niños and the PDO can occur in combination. The water elevations changes from each factor may each be only about a foot or less (less than 0.3 meters), but they can cause changes in the water level over a time period of days, months, or a few years -- far more rapidly than sea-level rise. In combination, they can cause a significant localized increase in water level.

When high water conditions occur in combination with high tides, and with coastal storms, the threat of coastal flooding, wave impacts and erosion also increases. These conditions can be additive, as shown in Figure 12. Also, these changes in water level will continue to be important to the overall water level conditions along the California coast and they need to be examined in conjunction with possible changes due to regional sea-level rise.

As stated earlier, estimates of surge, El Niño and PDO water elevation changes are developed primarily from historic records. There are no state-wide resources for this information, although it may be included in one of the regional Coastal California Storm and Tide, Wave Studies prepared by the US Army Corps of Engineers. General guidance on water level changes that can be expected from surge and El Niños is also provided in Table 12.

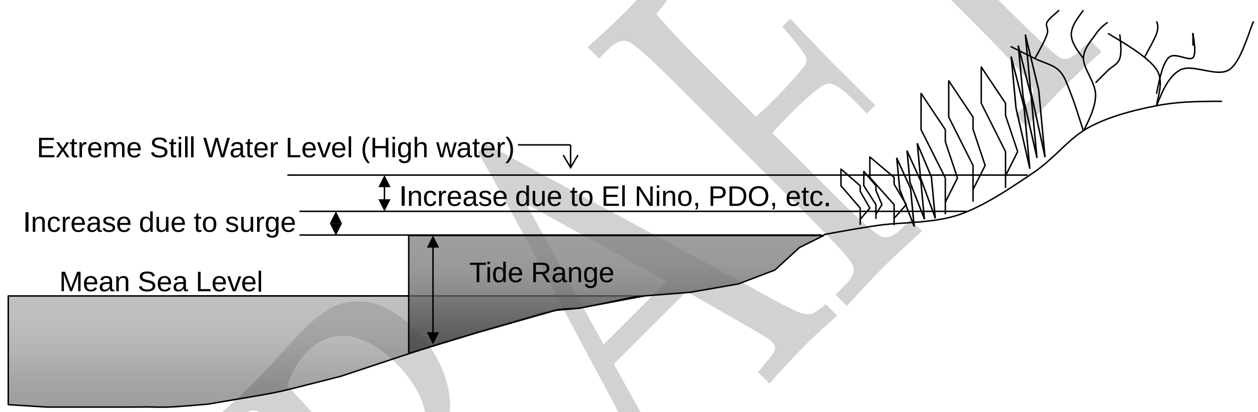

Figure 12. Changes to Extreme Still Water Level due to Surge, El Niños, PDOs, and such (Figure by L. Ewing, 2013).

Table 12. General Resources for Determining Still Water Elevation due to Surge, El Niños, PDOs.

Resource	Specifics of Information	Source
Sea-Level Rise Affecting Marshes Model (SLAMM)	Simulates the dominant processes involved in wetland conversions and shoreline modifications during long-term sea-level rise. Map distributions of wetlands are predicted under conditions of accelerated sea-level rise, and results are summarized in tabular and graphical form.	http://www.warrenpinnacle.com/prof/SLAMM
NOAA Digital Coast Sea-Level Rise Viewer	Displays potential future sea levels within wetland areas, and provided visualizations for various amounts of sea-level rise. For bays and estuaries, it also provides information on inland areas with the potential to flood if existing barriers to water connectivity are removed or overtopped. Communicates spatial uncertainty of mapped sea-level rise, overlays social and economic data onto sea-level rise maps, and models potential marsh migration due to sea-level rise. Maps do not include any influence of beach or dune erosion.	http://www.csc.noaa.gov/digitalcoast/tools/slrviewer
Pacific Institute Sea-Level Rise Maps	Downloadable PDF maps showing the coastal flood and erosion hazard zones from the 2009 study. Data are overlayed on aerial photographs and show major roads. Also available are an interactive online map and downloadable maps showing sea-level rise and population and property at risk, miles of vulnerable roads and railroads, vulnerable power plants and wastewater treatment plants, and wetland migration potential.	http://www.pacinst.org/reports/sea_level_rise/maps/ For the 2009 report "The Impacts of Sea-Level Rise on the California Coast" visit: http://www.pacinst.org/reports/sea_level_rise/report.pdf
Cal-Adapt – Exploring California's Climate	Shows coastal areas that may be threatened by flooding from a 1.4 meter rise in sea level and a 100-year flood event. Maps do not now include any influence of beach or dune erosion or existing protective structures.	http://cal-adapt.org/sealevel/

***Outcomes from Step 5**: Step 5 provides estimates of water elevations that can result from surge, El Niños and PDOs. When combined with the sea level changes to the tidal range, developed in Step 4, this can provide information on the extreme still water level. For most open coast situations, this information will be used to inform further project analysis and planning that examines erosion, surge and storm conditions.*

Step 6 – Estimate Beach, Bluff and Dune Change from Erosion

Predictions of future beach, bluff, and dune erosion are complicated by the uncertainty associated with future waves, storms and sediment supply. As a result, there is no accepted method for predicting future beach erosion. At a minimum, projects should assume that there will be inundation of dry beach and that the beach will continue to experience seasonal and inter-annual changes comparable to historic amounts. When there is a range of erosion rates from historic trends, the high rate should be used to project future erosion with rising sea level conditions. For beaches that have had a relatively stable long-term width, it would be prudent to also consider the potential for greater variability or even erosion as a future condition. For recent studies that provide some general guidance for including sea-level rise in an evaluation of bluff and dune erosion, see, for example, Heberger et al. (2009) or Revell (2011). Other approaches that recognize the influence of water levels in beach, bluff, or dune erosion can also be used. Table 13, at the end of this section, provides some resources that can be used for projecting future erosion.

The following sections discuss specific concerns associated with beach, bluff and dune erosion and are provided to acquaint readers to the main issues associated with each system. Readers with a strong background in coastal systems may want to skim or skip the rest of this section.

Beach Erosion

Beach erosion and accretion occur on an on-going basis due to regular variability in waves, currents and sand supply. The movement of sand on and off of beaches is an ongoing process. Along the California coast, periods of gradual, on-going beach change will be punctuated by rapid and dramatic changes, often during times of large waves, or high streamflow events.

The overall dynamics of beach change have been described many times[40]. Sand moves both on and off shore as well as along the shore. Normal sources of sand to a beach are from rivers and streams, bluff erosion or gullies, and from offshore sand sources. Sand leaves a beach by being carried downcoast by waves and currents, either into submarine canyons or to locations too far offshore for waves to move it back onto shore. Beaches are part of the larger-scale sediment dynamics of the littoral cell, and in very simple terms beaches accrete if more sand comes onto the beach than leaves and beaches erode if more sand leaves than is added. Changes in sand supply are a major aspect of beach change.

[40] See for example, Bascom, 1980; Komar, 1998; Griggs et al., 2005.

Beach changes are often classified as being either seasonal or long-term/inter-annual changes. Seasonal changes are the shifts in beach width that tend to occur throughout the year and are usually reversible. Beaches tend to widen during the late spring and summer as gentle waves carry offshore sand up, onto the beach. Then during late fall and winter, beaches tend to become narrower as more high energy waves carry sand away from the beach and deposit in offshore bars. This is followed by beach widening as gentler waves again bring sand landward, building up a wider dry-sand summer beach. These changes are considered seasonal changes, and if the beach widths return to the same seasonal width each year, then the beach experiences seasonal changes but no long-term or inter-annual changes. If the seasonal beach widths become progressively narrower, these changes become long-term or inter-annual change and suggest a long-term beach change trend – accretion if the beach is widening and erosion if the beach is narrowing.

If development is at or near beach level, erosion of the beach can expose the development to damage from wave forces, flooding, and foundation scour. And waves that hit the coast bring with them vegetation, floating debris, sand, cobbles, and other material. This material can act like projectiles, adding to the flood damage and forces from the waves.

At present, about 66% of the California beaches have experienced erosion over the last few decades, with the main concentration of eroding beaches occurring in southern California (Hapke et al., 2006). This erosion has been due to a combination of diminished sand supplies and increased removal of sand by waves and currents. With rising sea level, beach erosion is likely to increase, due to both increased wave energy[41] that can carry sand offshore or away from the beach, and to decreased supply of new sediments to the coast[42].

There are several elements that will contribute to the effects of sea-level rise on seasonal and inter-annual beach change. There will be the changes to the beach due to inundation by rising water levels, as shown in Figure 13. (See discussion on inundation for more information on how to determine this change.) If the beach cannot migrate inland to accommodate these changes, then the inundation will result in a direct loss or erosion of beach width. This will result in a narrower seasonal beach as well as inter-annual loss of beach.

Seasonal and inter-annual beach conditions will also be affected by changes to waves and sediment supply. Since waves are sensitive to bottom bathymetry, changes in sea level may change the diffraction and refraction of waves as they approach the coast, and change the resulting mixture of beach-accreting and beach-eroding waves. However, the influence of climate change (not just rising sea level) on wave conditions, through changes in wave height, wave direction, storm frequency and storm intensity will likely be far more significant than the slight changes from bathymetric changes. In addition, changing precipitation patterns will modify the amount and timing of sediment delivery to the beach.

[41] In shallow water, wave energy is proportional to the square of the water depth. As water depths increase with sea-level rise, wave energy at the same location will likewise increase.
[42] Many parts of the developed coast are already experiencing drops in sand supplies due to upstream impoundments of water and sediment, more impervious surfaces, and sand mining.

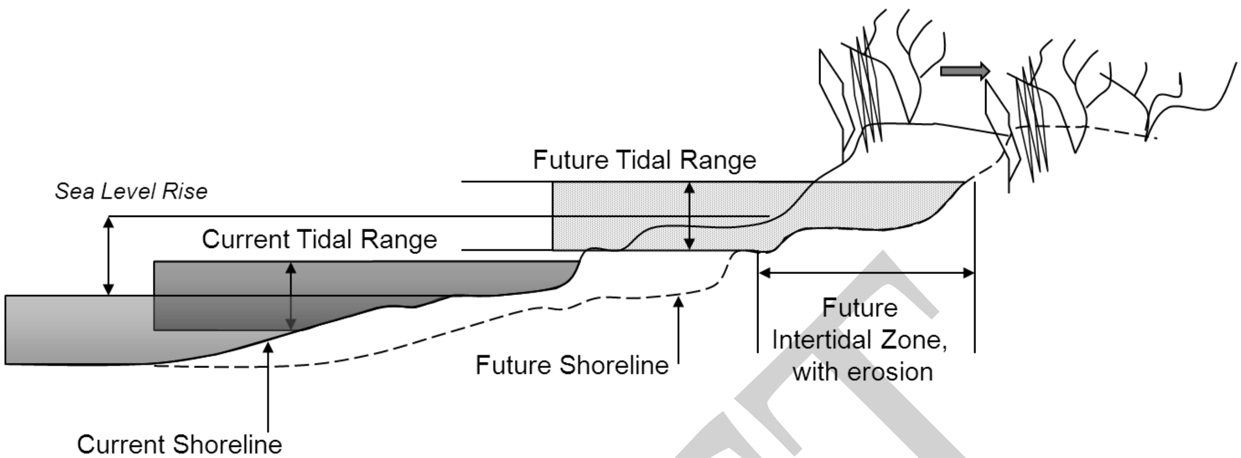

Figure 13. Changes to the Intertidal Zone with Sea-level rise and Erosion, without Wave Impacts (Figure by L. Ewing, 2013).

Bluff Erosion

A second type of erosion occurs on coastal bluffs[43]. There is no fully-accepted methodology for estimating future bluff erosion with sea-level rise. Guidance for coastal analysts in Hawaii is to assume erosion will increase as a proportion of historic erosion. (Hwang, 2005) One approach used in the past by the Commission has been to use the high range of historic erosion rates to represent average future trends. A more process-based methodology, used in the Pacific Institute study of erosion due to rising sea level, is to correlate future erosion rates of bluffs with increased frequency of wave impacts (Heberger et al., 2009; Revell, 2011). This approach assumes that all bluff erosion is due to wave impacts and erosion rates will change over time as the beach or bluff experiences more frequent or more intense wave attack. Such an approach should be considered for examining bluff erosion with rising sea level. Other approaches that recognize the influence of water levels in beach, bluff, or dune erosion can also be used.

Bluff retreat occurs due to many different mechanisms. Landslides, slumps, block failures, gullies, and rilling are examples of bluff retreat. At the most basic level, bluff retreat or collapse occurs when the forces leading to collapse of the bluff face are stronger than the forces holding the bluff in place. Forces causing bluff retreat can include earthquakes, wind, burrowing animals, gravity, rain, surface runoff, groundwater, and sheet flow. Coastal bluffs have the added factor of wave attack, a factor that is not present for inland bluffs. Resistance to collapse is mainly a characteristic of the bluff material. For example, granitic bluffs like those along the Big Sur coast retreat at a much slower rate than the soft sandstone and marine terrace bluffs of Pacifica.

[43] Bluffs can be built or expanded during interglacial cycles or following seismic uplift. Many of the marine terraces that are visible along the California coast are remnants of past beach areas that have been uplifted to become bluffs and cliffs. However, natural bluff rebuilding is a millennial or multi-millennial process, and it will not occur during the time periods over which most development projects are evaluated.

Coastal bluff erosion can occur throughout the year, but it often occurs during or after storm periods, when the dry beach will be narrow or non-existent. When coastal bluffs are fronted by wide sand beaches, most waves break on the beach face and the beaches protect the bluffs from direct wave attack. When the beach is narrow, there is less buffering of the wave energy and waves can break directly against the bluffs. A general depiction of bluff retreat with rising sea level is provided in Figure 14.

Bluff retreat is often episodic – the bluff may be stable for a number of years and then retreat by tens of feet in a few hours or a few days. If the changes to a bluff are examined through endpoint analysis – i.e. looking first at the initial position of the bluff and then at the position of the bluff sometime in the future, researchers can determine the amount of retreat that has occurred during the time from the initial to final positions. This gives information on an average retreat rate that has occurred, but gives no information about the conditions leading to the retreat, or the progression of retreat and no retreat. The average retreat rates can give some indication of likely future changes, but they provide little information about when the next retreat episode might occur or how large it might be.

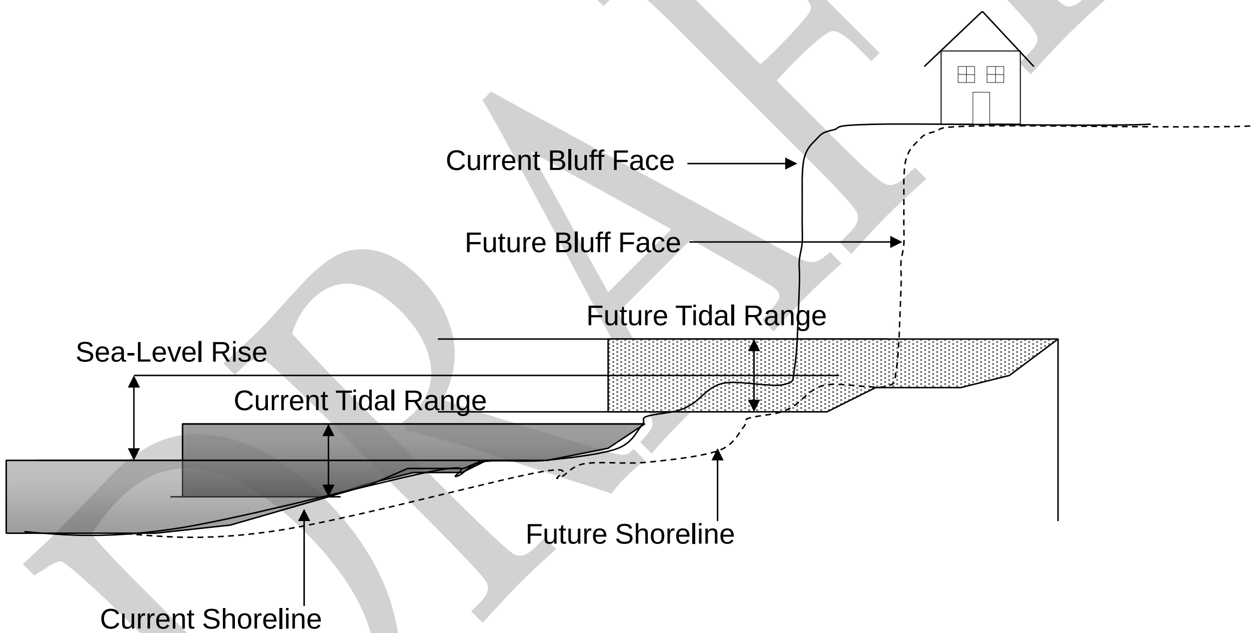

Figure 14. Bluff Erosion with changes in sea level (Figure by L. Ewing, 2013).

<u>Dune Erosion</u>

Just as there is no fully accepted methodology for estimating changes to beach or bluff erosion with sea-level rise, there is no fully-accepted methodology for dune erosion. A methodology somewhat similar to that for bluff erosion has been developed for dunes (Heberger et al., 2009; Revell, 2011), and such an approach should be considered for examining dune erosion with rising sea-level. Other approaches that recognize the influence of water levels in beach, bluff or dune erosion can also be used.

Dune erosion occurs when the waves break at or near the dunes, pulling sediment out of the dune. This process does deposit sand onto the beach or in the nearshore area, but can result in short term dune retreat. If sand is not returned to the dunes following these periods of short-term retreat, the sand losses will contribute to long-term dune erosion. When development is on the coastal dune, building damage occurs when the dune retreats back to the location of development, either through reversible, short-term retreat or long-term erosion. As with bluff erosion, the Pacific Institute work (Heberger et al., 2009) examined sea level related changes in dune erosion rates and has provided a methodology that can be considered in examining future changes to dune erosion with increased sea-level rise.

For individual cases, determinations of future retreat risk are based on the site-specific conditions, and professional analysis and judgment. However, the lack of information about the contributions of all the erosive forces to dunes and the beach-dune interactions makes it challenging to anticipate future changes to coastal dune retreat due to rising sea level and increased wave forces. As with beaches and bluffs for most situations, these historic conditions provide a lower limit for future dune retreat, or the upper limit of advance for those sites that are now experiencing accretion or quasi-stability. Projections of future erosion should either (1) use the high range of historic erosion, (2) develop a sea-level rise influenced erosion rate, as done by Heberger et al., 2009 or Revell, 2011, or (3) develop another approach that considers shoreline changes that are likely to occur under rising sea level conditions.

Table 13. General resources for information on beach, bluff and dune erosion

Resource	Specifics of Information	Source
Aerial Photographs	Useful for general information on shoreline trends Ortho-rectified photos can help quantify trends	California Coastal Records Project - www.californiacoastline.org; Huntington Library; Local Libraries
LIDAR	Fairly detailed topography Can provide GIS layers for current conditions Comparable with LIDAR data sets for temporal changes	NOAA Coastal Services Center - http://www.csc.noaa.gov/data/index.html
USGS National Assessment of Shoreline Change with GIS Compilation of Vector Shorelines	Statewide inter-annual beach and bluff erosion. GIS shorelines available for sandy shorelines & cliff edge. Shorelines show historic changes. Long-term (70 to 100 years); short-term (25 to 50 years. No projections of future erosion rates.	Sandy Shorelines -- Open File Report 2006-1219; GIS Data in Open File 2006-1251 http://pubs.usgs.gov/of/2006/1219 and http://pubs.usgs.gov/of/2006/1251 Bluff Shorelines – Open File Report 2007-1133; GIS Data in Open File 2007-1251 http://pubs.usgs.gov/of/2007/1133 and http://pubs.usgs.gov/of/2007/1112
Regional Sediment Management Studies	Summaries of seasonal and long-term erosion studies	CSMW Website; http://dbw.ca.gov/csmw/default.aspx

Corps of Engineers, Coast of California Studies	Summaries of seasonal and long-term erosion studies	Studies for many regions are available through an internet search. Addresses are too numerous to list here.
Beach Profiles and Surveys	Detailed Beach or Bluff changes with time	NOAA, Coastal Services Center - http://www.csc.noaa.gov/data/index.html; US Army Corps of Engineers; Regional Beach Studies; University Studies
The Impacts of Sea-level rise on the California Coast (Pacific Institute Report)	Show expected changes to bluff position over time for sea-level rise of 1.4 meters from 2000 to 2100 for California coast from Oregon border through Santa Barbara County.	Pacific Institute Web site - http://www.pacinst.org/reports/sea_level_rise/maps/
CoSMoS	COSMOS is a tool for predicting climate change impacts from storms. It does not predict long-term erosion, but can provide general information for short-term, storm-drive beach changes. Only available, at present, for the central coast.	http://data.prbo.org/apps/ocof/

Outcome from Step 6: *Step 6 provides projections of future long-term beach, bluff or dune erosion that takes into account sea-level rise. For locations without any influence from storm surge, or wave energy, the identification of the extent of beach, bluff or dune erosion may be sufficient for project analysis and planning efforts. This projected new erosion area may also be useful for anticipating the appropriate setback distance for otherwise stable land forms (If slope stability if a concern, refer to Commission guidance on setbacks (Johnsson 2005. Available: http://www.coastal.ca.gov/W-11.5-2mm3.pdf)). For most open coast situations, this information will be used to inform further project analysis and planning that examines erosion, surge and storm conditions.*

Step 7 – Determine Wave, Storm Wave, Wave Runup and Flooding Conditions

The main concerns with waves, storm waves, and runup are flooding and wave impacts. Flooding is the temporary wetting of an area by waves, wave runup, surge, atmospheric forcing (such as water elevation during El Niño events) and, at river mouths, the combination of waves and river flows. Wave impacts occur when high-energy waves, often associated with storms, reach backshore areas or development. Coastal flooding and wave impacts are worst when they coincide with high water level events (high tide plus high inundation). As sea level rises, inundation will move inland, and so will flooding and wave impacts. Beach erosion will aggravate these conditions and add to the inland extent of impacts.

Flooding: In most situations, factors that result in high water conditions, such as tides, surge, El Niños, and PDOs, should be used to determine flood conditions and flood areas, as shown below. If the area is exposed to storm waves, these forces should be examined as well.

Future Flooding = Future Higher High Tide + Surge + Forcing + Wave Runup

Flooding Areas = Flooding + seasonal eroded beach + long-term beach erosion

Waves: Wave impacts depend greatly upon storm activity – both the intensity and the duration of the storm. Normally projects have used design wave conditions comparable to the 100-year event. For critical infrastructure or development with a long anticipated life expectancy it may be advisable to use a greater design standard, such as a 200-year or 500-year event. So, some proposed projects may want to adjust design waves or frequency of high energy waves to analyze the consequences of worsening wave impacts.

Wave impacts to the coast, to coastal bluff erosion, and to inland development should be analyzed under the conditions most likely to cause harm. Those conditions normally occur in winter when most of the sand has moved offshore, leaving only a reduced dry sand beach to dissipate wave energy. Since the development will be in place for a number of years, on beaches that will experience long-term erosion, the beach changes expected to occur over the life of the development should also be considered. Just as the beach conditions should be those least likely to protect from damage over the life of the development, so too should the water level conditions be those most likely to contribute to damage over the life of the development. Waves that cause significant damage during high tide will be less damaging during low tide; all other things being equal, waves will cause more inland flooding and impact damage when water levels are higher. Since water levels will increase over the life of the development due to rising sea level, the development should be examined for the amount of sea-level rise (or a scenario of sea-level rise conditions) that is likely to occur throughout the expected life of the development. Then, the wave impact analysis will examine the consequences of a 100-year design storm event, with water levels likely to occur due to high water conditions and sea-level rise, and with a long-term and seasonally eroded beach.

Eroded Beach Conditions = seasonal erosion + long-term erosion*

High Water Conditions = High tide + relative sea-level rise* + atmospheric forcing

Wave Conditions = 100-year Design Storm + High Water + Eroded Beach

* The time period for both long-term erosion and relative sea-level rise will be at least as long as the expected life of the development.

The remaining discussion provides general information about waves, the California wave climate and coastal flooding. It is provided to acquaint readers to the main issues associated with waves and coastal flooding. Readers with a strong background in waves or coastal processes may want to skim or skip the rest of this section.

Waves, like tides, cause constant changes to the water levels that are observed at the coast. The rhythmic lapping of waves on the beach during summer can be one of the joys of a beach visit. At other times of the year, waves can increase in size and energy and damage or destroy buildings, and cause erosion of bluffs and cliffs. Routine ocean waves are generated by wind blowing across the surface of the water. Once generated, waves can travel far from their source, combining with waves generated from other locations, resulting in the rather erratic and choppy water levels that are seen in most of the ocean. But, as waves move into shallow water and approach land, they take on a more uniform appearance, aligning somewhat parallel to the shoreline through processes of refraction and diffraction. During most of the year, moderate short-period waves break once they are in water depths of approximately 1.3 times the wave height.

Storm Waves: During storm conditions, winds can transfer large amounts of energy into waves, increasing the wave height, length and period. Energy transfer to waves depends upon three conditions, the wind energy that is available to be transferred to the water (intensity), the length of time over which the wind blows (duration), and the area over which the wind blows (the fetch). As any of these conditions increase, the energy in the waves will increase, as will the energy that these waves bring to the coastline. Coastal scientists separate waves that are generated far from the coast (swell) from waves that are locally generated (seas). Storms in the mid-Pacific can cause storm-like wave conditions along the coast, even when there are no storms in the area. Likewise, a local storm can cause storm waves along one part of the coast while waves in other sections of the coast may be fairly mild.

Some of the worst storm wave conditions occur when there are intense storms along a large portion of the coast, and when this large, distantly generated swell combines with local seas. This was the case during part of the 1982-83 El Niño storm season when waves from a distant storm combined with locally generated waves and made landfall during high tide. As a result, approximately 3,000 homes and 900 businesses were damaged, and 33 buildings were destroyed. Damages exceeded $100 million to structures and $35 million to public recreational infrastructure (in 1982 dollars) (Flick, 1998).

Wave Runup: Wave runup, as depicted in Figure 15, is the distance or extent that water from a breaking wall will extend up a beach or structure. Much of the wave energy will dissipate during breaking, but wave runup can also be damaging. The runup water moves quickly; it can scour or erode the beach, damage structures, and flood inland areas.

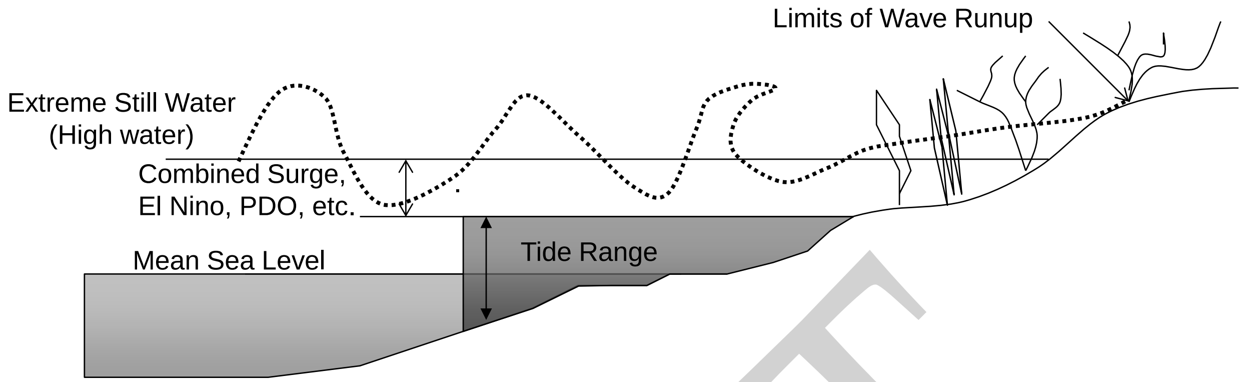

Figure 15. Wave Runup combined with Extreme Still Water (High Water) (Figure by L. Ewing, 2013).

Damage from waves and wave runup may increase in the future, due both to rising sea level and to changes in storm intensity and frequency. Waves will break farther landward when water levels are higher. Therefore, increased water levels due to tides, surge, ENSO or PDO variability, or sea-level rise will enable more wave energy to reach the beach, back shore, or inland development. The higher water levels do not change the waves. Rather, higher water levels change the point of impact, the extent of runup, and the frequency of wave impact. In locations where high waves now hit the coast, that frequency will increase. In locations where high waves rarely hit the coast, exposure to wave impacts will increase. Increased exposure to wave impacts or wave runup can cause a greater risk of flooding, erosion, and/or bluff failure.

Summary: Coastal flooding is a significant problem now and it will increase with rising sea level. At present, about 210,000 people in California are living in areas at risk from a 100-year flood event (Heberger et al., 2009). A rise in sea level of 55 inches (1.4 meters) and with no change in development patterns or growth along the coast, could put 418,000 to 480,000 people at risk from a 100-year flood (Cooley et al., 2012). Increases in storm intensity, or in the density of development in flood-prone areas, will increase the number of people at risk from flooding.

The frequency and intensity of high wave events depends upon the storm conditions that generate the waves. There is less consistency in the output of climate models related to projections of future storm conditions than there has been for temperature projections. A recent report on coastal flooding from 2000 to 2100 for the California coast has found that “storm activity is not projected to intensify or appreciably change the characteristics of winter nearshore wave activity of the twenty-first century.” (Bromirski et al., 2012, p. 33) This continuation of current storm conditions is not, however, an indication that storms will not be a problem in the future. Storm damage is expected to continue, and, if sea-level rise by the end of the twenty-first century is close to the high projections of about 55 inches (1.4 meters), “coastal managers can anticipate that coastal flooding events of much greater magnitude than those during the 1982-83 El Niño will occur annually.” (Bromirski et al., 2012, p. 36)

For most situations, the 100-year storm event will be used as the design storm. This is equivalent to a storm with a 1% annual probability of occurrence. However, most development does not stay for only a year and this probability of occurrence grows over time such that there is a 25% probability of occurrence during 25 year and over 55% probability that this storm will occur at least once during a 75 year period. Even so, the 100-year storm event, like the 100-year flood event, is often used as a design standard for development. However, for structures with a very long projected life or for which storm protection is very critical, a larger, 200-year or 500-year event might be appropriate.

Table 14 lists many of the resources that are available for finding regional or state-wide information on waves and flooding. Local communities often may have records of major erosion episodes or flood events.

Table 14. General Resources for Flooding and Wave Impacts

Resource	Specifics of Information	Source
CDIP (Coastal Data Information Program)	Current and historic information on wind, waves, and water temperature, wave and swell models and forecasting. As of 2013, there are 19 active stations along the California coast.	http://cdip.ucsd.edu/
Flood Insurance Rate Maps (FIRMs)	FEMA is updating coastal flood maps. Existing FIRMs are based on 1980s topography; flooding includes seasonal beach change but not long-term erosion. Maps do not include sea-level rise. Inclusion of a site shows a flood hazard; but exclusion does not necessarily show a lack of flood hazard.	FEMA Flood Map Center
Regional Sediment Management Studies	Some studies show elements of beach flooding and wave impacts	CSMW Website - http://dbw.ca.gov/csmw/default.aspx
Cal-Adapt – Exploring California's Climate	Shows coastal areas that may be threatened by flooding from a 1.4 meter rise in sea level and a 100-year flood event. Maps do not now include any influence of beach or dune erosion or existing protective structures.	http://cal-adapt.org/sealevel/
FEMA Flood Hazard Mapping Guidance	Subsection D.2.8 provides guidance for calculating wave runup and overtopping on barriers. There are special cases for steep slopes and where runup exceeds the barrier or bluff crest.	http://www.fema.gov/library/file?type=publishedFile&file=frm_cfhamagd28.pdf&fileid=73be5370-c373-11db-a8db-000bdba87d5b
US Army Corps of Engineers, Coastal Engineering Manual	Detailed information on all aspects of deepwater wave transformation, shoaling, runup, and overtopping.	http://chl.erdc.usace.army.mil/cem

European Overtopping Manual	Descriptions of available methods for assessing overtopping and its consequences. Provides techniques to predict wave overtopping at seawalls, flood embankments, breakwaters and other shoreline structures facing waves. Supported by web-based programs for the calculation of overtopping discharge and design details	http://www.overtopping-manual.com/
CoSMoS	COSMOS is a tool for predicting climate change impacts from storms. It does not predict long-term erosion, but can provide general information for short-term, storm-drive beach changes. Only available, at present, for the central coast.	http://data.prbo.org/apps/ocof/
OCOF	(See CoSMoS)	http://data.prbo.org/apps/ocof/

Outcome from Step 7: *Step 7 provides projections of future flooding and wave impacts resulting from waves, storm waves and runup, that takes into account sea-level rise.*

Step 8 – Examine potential flooding from extreme events

Extreme events[44], by their very nature, are beyond the normal events that are considered in most shoreline studies. For an individual storm, that might be one with an intensity at or above the 100-year event. Or, extreme events could arise from a series of large, long-duration storms during high tides or from a local storm that coincides with the arrival of distant swell and high tides. Global sea-level rise greater than that projected to occur by 2100, when combined with a large storm during normal tides could develop into an extreme event. Rapid subsidence, as might happen along the northern CA coast during a Cascadia Subduction Zone earthquake, would be an extreme event. These are the outlier events that need to be anticipated and their consequences will need to be considered in planning and project analysis. In many situations, this consideration might be qualitative with consideration for the consequences that could happen if an extreme event does occur and opens up opportunities to address some of those consequences through design and adaptation.

In California, there may be some worsening of extreme precipitation and inland flooding from projected changes to atmospheric rivers. In general, however, future extremes are likely to be comparable to the extremes of today, but with the added influence of sea-level rise. Extreme

[44] In its report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation, the IPCC defines extreme events as "a facet of climate variability under stable or changing climate conditions. They are defined as the occurrence of a value or weather or climate variable above (or below) a threshold value near the upper (or lower) ends ("tails") of the range of observed values of the variable" (IPCC, 2012).

storm waves or floods can be addressed with the guidance provided earlier, except that the extreme storm conditions would be used. For tsunamis it is recommended that, for most situations, the appropriate projection of sea-level rise be added to the currently projected inundation level from tsunamis. This will provide a close approximation for future inundation from extreme tsunamis. If detailed analysis of future tsunami impacts is needed, someone experienced in modeling tsunami waves should be contacted.

Tsunamis: Tsunamis are large, long-period waves that can be generated by submarine landslides, large submarine earthquakes, meteors, or volcanic eruptions. They are rare events, but can be extremely destructive when they occur. There has been no research that suggests tsunamis could worsen in the future through some link with climate change. However the extent of tsunami damage will increase as rising water levels allow tsunami waves to extend farther inland. Thus the tsunami inundation zone will expand inland with rising sea level. There is no direct connection between tsunamis and either sea-level rise or climate change. But, for coastal areas that are at risk from tsunamis, the inundation zone will change as sea-level rises.

The detailed changes to the inundation zone with rising sea level would need to be determined by modeling. However, modeling of long-waves, such as tsunamis, is a specialized area of coastal engineering, and will not be covered in this general guidance. For most situations, it will be sufficient to get information on possible inundation from the most recent tsunami inundation maps (currently on the Department of Conservation website, http://www.conservation.ca.gov/cgs/geologic_hazards/Tsunami/Inundation_Maps/Pages/Statewide_Maps.aspx). As a rough approximation, the change to the inundation level can be estimated as equal to the change water elevation due to sea level. So, a one-foot rise in sea level could be assumed to result in a one-foot rise in the inundation elevation. However, in many places, particularly shallow bays, harbors, and estuaries, the change in tsunami inundation zone is likely to scale non-linearly with sea-level rise and require careful modeling. In areas with high tsunami hazards, or where critical resources are at risk, a site-specific analysis of sea-level rise impacts on tsunami hazards is crucial and someone experienced in modeling tsunami waves should be contacted.

Summary: Many different factors affect the actual water levels that occur along the coast and resulting hazards. In California, waves and tides have the largest routine effect on water levels. Tsunamis may have a very large, but infrequent effect of water levels. Sea-level rise will affect water levels all along the coast. Until the mid-century, the effects of tides and storms are expected to have the biggest effect on local water levels, with sea-level rise being a growing concern. For the second half of the century, sea-level rise is expected to become increasingly important for water levels and in damages to inland areas from flooding, erosion and wave impacts. Table 15 provides a general characterization of all the factors that can affect local water levels, with general estimate of their range and frequency of occurrence.

Table 15. Factors that Influence Local Water Level Conditions

Factors Affecting Water Level	**Typical Range for CA Coast (m)**	**Typical Range for CA Coast (feet)**	**Period of Influence**	**Frequency**
Tides	1 – 3	3 – 10	Hours	Twice daily
Low pressure	0.5	1.5	Days	Many times a year
Storm Surge	0.6 – 1.0	2 – 3	Days	Several times a year
Storm Waves	1 - 5	3 – 15	Hours	Several times a year
El Niños (within the ENSO cycle)	< 0.5	<1.5	Months - Years	2-7 years
Tsunami waves	6 – 8	20 – 26	Minutes to Hours	Infrequent but unpredictable
Historic Sea Level, over 100 years	0.2	0.7	On-going	Persistent
NRC State-wide Sea Level Projections 2000 – 2050	0.2 – 0.4	0.7 – 1.4	Ongoing	Persistent
NRC State-wide Sea Level Projections 2000 - 2100	0.1 – 1.43 m (North of Cape Mendocino) 0.42- 1.67 m (South of Cape Mendocino	0.3 – 4.69 ft (North of Cape Mendocino) 1.38 – 5.48 ft (South of Cape Mendocino)	Ongoing	Persistent

NOTE: All values are approximations. The conversions between feet and meters have been rounded to maintain the general ranges and they are not exact conversions.
Sources: Flick, 1998; NRC, 2012; Personal communications from Dr. Robert Guza (Scripps Institution of Oceanography) and Dr. William O'Reilly (Scripps Institution of Oceanography and University of California, Berkeley); and personal judgment of staff.

Outcome from Step 8: *Step 8 provides projections of potential flooding from extreme events including rapid subsidence, extreme precipitation, and tsunamis.*

APPENDIX C. ADAPTATION MEASURES

An adaptation measure is an action that minimizes risks from sea-level rise. Examples include changes in siting and design requirements, elevating the foundation of an individual structure, or moving a structure inland. Many adaptation measures benefit multiple coastal resources, and some adaptation measures fit into multiple categories, as shown the in tables below. Implied in each of these measures is the goal to protect and restore current and future coastal and marine resources and existing development, in accordance with the policies of the Coastal Act.

The Commission staff has compiled a list of potential adaptation measures for use in coastal development permitting and planning efforts and divided the measures into seven categories based on the requirements of the California Coastal Act. The adaptation measures in each category are listed in alphabetical order in the following tables.[45]

1. **Community Level Planning** – Table 16
2. **Site Development Standards and/or Mitigation –** Table 17
3. **Shoreline Protection and Management –** Table 18
4. **Natural Resources –** Table 19
5. **Water Quality and Water Supply Management –** Table 20
6. **Other Adaptation Measures –** Table 21

Description of Adaptation Measures

1. Community Level Planning Measures

Community level planning includes adaptation measures that are designed to guide development at a community, neighborhood, or hazard area scale. The measures generally apply to more than one parcel. Community level planning measures include:

- Concentration of development/Smart Growth
- Design standards
- Hazard zoning/ Overlay zones
- Land division requirements
- Transfer of Development Rights programs (TDR)
- Preserving open space
- Conservation easement programs
- Regional Sediment Management (RMS) programs

[45] The list of adaptation measures and descriptions were adapted and compiled various sources, including NOAA's "Adaptation to Climate Change: A Planning Guide for State Coastal Managers" (NOAA, 2010), Georgetown Climate Center's "Adaptation Tool Kit: Sea Level Rise and Coastal Land Use" (Grannis, 2011), EPA's Climate Ready Estuaries "Synthesis of Adaptation Options for Coastal Areas" (EPA, 2009), and Coastal Commission staff (personal communication, 2012-2013).

Table 16. Community Level Planning

Adaptation Measure	Description	Applicability to sea-level rise
Concentration of development/ Smart Growth	Require development to concentrate in areas that can accommodate it without significant adverse effects on coastal resources. This action should be consistent with Section 30250 and other policies of the Coastal Act.	Concentrate new development away from areas that are highly vulnerable to sea-level rise. This action is also applicable to CDPs for multiple lots.
Design standards	Establish and implement standards for building construction that minimize risks from flooding and erosion and increase resilience to extreme events.	LCPs should establish building standards to minimize hazards from sea-level rise. Standards may include higher base flood elevations, floating structures, and easily moveable structures, as well as strategies to reduce impacts from flood waters, such as green infrastructure and pervious surfaces.
Hazard zoning/ Overlay zones	Requires that new development is sited and designed to avoid highly hazardous or environmentally sensitive areas.	Update land use designations and zoning to identify areas that are vulnerable to sea-level rise impacts and to develop special regulations for those areas. Zoning regulations will need to be certified through an LCP Amendment.
Land division Requirements	Establish requirements for land divisions, lot creation, and lot line adjustments.	LCPs should limit subdivisions in hazard areas or require lots to meet specific standards in order to protect resources and prevent hazards. Also applicable to CDP.
Transfer of Development Rights programs (TDR)	Restrict development in one area (“sending area”) and allow for the transfer of development rights to another area more appropriate for intense use (“receiving area”).	LCPs can establish policies to implement a TDR program to restrict development in areas vulnerable to sea-level rise and allow for transfer of development rights to inland parcels with less vulnerability to hazards.
Preserving open space	Preserve land for its ecological or recreational value. Includes prohibiting development and any uses that conflict with ecological preservation goals.	LCPs can promote the preservation of open space, especially undeveloped areas vulnerable to sea-level rise impacts, through zoning restrictions or establishment of a defined urban/rural boundary.

Conservation easement program	Establish a formalized program to identify, acquire, and manage areas appropriate for some form of conservation protection. The program might develop standard agreements to be used for easements and chain of title, and identify the entities that could hold the easements.	LCPs can use a conservation easement program to limit or restrict development on portions of a lot parcel that would be most vulnerable to sea-level rise impacts. Parcel by parcel application would be accomplished through the CDP.
Regional Sediment Management (RSM) Program	Manage sediment to benefit a region, allow use of natural processes to solve engineering problems. To be most effective RSM will include the entire watershed, account for effects of human activities on sediment and protect and enhance coastal ecosystems.	LCPs can include support for development of an RSM program, and, once developed, supporting the management efforts identified by the RSM, and requiring that the plans be updated to include changes from sea-level rise. Natural boundaries for RSM may overlap with portions of several LCPs, so cooperation may be needed for best implementation. Individual actions would be accomplished through a CDP.

2. Site Development Standards and/or Mitigation

Site development standards are adaptation measures that are designed to reduce risks from sea-level rise at the individual parcel level. Mitigation measures are actions required as part of a coastal development permit to minimize hazards or adverse impacts to coastal resources. These include:

- Conditional permitting of shoreline protection structures
- Conservation easements
- Infrastructure-service protection
- Permit conditions
- Real estate disclosure
- Redevelopment restrictions
- Setbacks
- Siting and design

Table 17. Site Development Standards and/or Mitigation

Category	Description	Applicability to sea-level rise
Conditional permitting of shoreline protection structures	Add conditions to the shoreline protection permits, such as conditions that require the removal or modification of armoring in the future if need for protection or site conditions change.	Require shoreline protection to be removed, or considered for removal if the structure for which it was installed no longer exists or needs protection.
Conservation Easements	Provide a flexible mechanism by which a land trust or public entity can preserve land in its natural state while allowing land to remain in private ownership.	Where applicable, conservation easements can be required as a condition of a CDP. Also, LCPs can include policies to specify when such mitigation is appropriate or required.
Infrastructure-service protection	Establish measures that ensure continued function of critical infrastructure, or the basic facilities, services, networks, and systems needed for the functioning of a community.	LCPs can identify critical infrastructure vulnerable to hazards from sea-level rise, and can include criteria for managed relocation of at-risk facilities and direction to ensure continued function of critical infrastructure given sea-level rise and extreme storms. Can involve repair and maintenance, elevation or spot-protection of key components or fortification of structures where consistent with the Coastal Act.
Permit conditions	Conditionally approve a CDP to identify and require resource protective mitigation necessary to address impacts associated with locating development in an area subject to sea-level rise.	To mitigate impacts associated with locating new development in areas subject to sea-level rise, CDPs can include conditions that require: removal of structures if threatened, conservation easements, flood protection measures commensurate with rising sea level, and waiver of any rights to future shoreline protection.
Real estate disclosure	Require sellers of real estate to disclose certain property defects to prospective buyers prior to close. This action enables potential buyers to make informed decisions regarding the level of impacts they may experience.	Disclosures should include information about known current and potential vulnerabilities to sea-level rise.

Redevelopment restrictions	Limit the extent of redevelopment that can occur in hazardous areas without a Coastal Development Permit.	LCPs should clarify the definition of redevelopment so that in areas vulnerable to sea level hazards, redevelopment will not increase non-conformance and that eventually, uses will convert to conforming through permitted redevelopment.
Setbacks	Set building restrictions that limit the portions of a lot that can be used for development. When used for hazard concerns, they are normally defined by a measurable distance from an identifiable location such as a bluff edge, line of vegetation, dune crest, or roadway.	LCPs can establish the general guidance (including the time period over which the setback should be effective) and criteria for establishing setbacks from bluffs and dunes that take into consideration changes in retreat due to sea-level rise. CPDs should require detailed, site-specific analyses to determine the size of the setback to take into account sea-level rise.
Siting and design	Determine where development can be located in order for it to be safe from hazards over the economic life of the development.	Incorporate sea-level rise into existing hazard analyses as part of the siting and design process.

3. Shoreline Management and Shore Protection

Shoreline management is a term used to describe actions to proactively preserve or manage a shoreline area. Measures include programs to nourish beaches, restore sediment supply, or maintain dunes. Shore protection includes measures that serve to reduce or eliminate upland damage from wave action or flooding during storms, and include natural measures such as living shorelines or placement of sand and hardened options such as seawalls or riprap. The shoreline management and shore protective measures include:

- Beach nourishment and replenishment
- Dredging management
- Dune management
- Hard Protection
- Living Shorelines
- Maintenance or restoration of natural sand supply
- Removal of shoreline protection structures
- Sediment management
- Soft protection
- Waiver of right to future shoreline protection

Table 18. Shoreline Management and Shore Protection Measures

Category	Description	Applicability to sea-level rise
Beach nourishment and replenishment	Placement of sand on beaches to reduce erosion, enhance recreation, or preserve or enhance the aesthetic and habitat value of beaches. Sand sources may include offshore dredge sites ("borrow areas"), nearby harbor or channel dredging projects, wetland restoration projects or inland development. Generally has fewer environmental drawbacks than hard armoring, but can negatively affect species living, feeding, and nesting on the beach, especially during and immediately after sand placement. Most effective for areas with some existing beach.	LCPs can identify locations where beach nourishment may be appropriate, possibly through a Regional Sediment Management program. If beach nourishment is appropriate, the LCP should establish criteria for the design, construction and management of the nourishment area that includes likely changes in beach conditions due to sea-level rise into beach nourishment and replenishment plans.
Dredging management	Dredging involves the removal of sediment from harbor areas to facilitate boat and ship traffic or from wetland areas for restoration.	Dredging management actions and plans may need to be updated to account for elevated water levels. LCPs and CDPs should facilitate delivery of clean sediment extracted from dredging to nearby beaches where needed.
Dune management	Establish management actions to maintain and restore dunes. Dunes provide buffers against erosion and flooding by trapping windblown sand, storing excess beach sand, and protecting inland areas, and they also provide habitat. Most effective for areas with some existing dune habitat and where there is sufficient space to expand a foredune beach for sand exchange between the more active (beach) and stable (dune) parts of the ecosystem.	LCPs can identify existing dune systems and develop or encourage the development of management plans to enhance and restore these areas, including consideration of ways that the system will change with rising sea level. CDPs for dune management plans may need to include periodic reviews so the permitted plans can be updated to address increased erosion from sea-level rise, and the need for increased sand retention and replenishment.

Hard Protection	"Hard" coastal protection is a broad term for most engineered features such as seawalls, revetments, cave fills, and bulkheads that block the landward retreat of the shoreline. Breakwaters, groins, and jetties may or may not be considered hard protection, depending upon their purpose and use with other "soft" protection.	LCPs can discourage the use of hard protection unless no other feasible alternative is available. LCPs should also develop design standards for the more frequently used hard protection and require designs that address or can be adapted to changing sea level. CDPs should require that hard protection be monitored for damage from sea-level rise hazards, that permits be re-opened after some time period to assess effectiveness in light of sea-level rise, and that removal options be incorporated into the design, in the event the structure may no longer be useful or appropriate in the future.
Living shorelines	Living shorelines are an approach to stabilize shoreline areas while maintaining valuable habitat and natural shoreline processes. These shorelines are designed with plants, sand, and limited amounts of rock to restore and enhance coastal habitats, promote sedimentation, and protect against shoreline erosion. They are effective in low-to-medium-energy coastal and estuarine areas and tidally influenced creeks, streams, and rivers.	LCPs can identify the local areas where living shorelines are most appropriate and develop guidance for implementation, monitoring, and evaluation. CDPs should require living shorelines where feasible and consistent with the Coastal Act. Require any living shorelines to take into account sea-level rise and storm events.
Maintenance or restoration of natural sand supply	Adjustment of the sediment supply has been one of the ways natural systems have accommodated changes from sea level. Maintenance or restoration of sediment involves identifying natural sediment supplies and removing and/or modifying existing structures or actions that impair natural sand supply, such as dams or sand mining.	LCPs should include policies and implementing standards that support nature-based responses to sea-level rise by maintaining and restoring natural sand supply. Where applicable, develop policies and standards to regulate sand mining, sand replenishment, and promote removal of dams or the by-passing of sand around dams. Plans should take into consideration changes in sand supply due to sea-level rise.

Removal of shoreline protection structures	When shoreline protection structures are no longer needed or are in a state of great disrepair, their removal can open beach or wetland areas to natural processes and provide for natural responses to sea-level rise.	LCPs can specify priority areas where shoreline protection structures should be removed, including areas where structures threaten the survival of wetlands and other habitat, or beaches, trails, and other recreational areas. Through the LCP, removal might be accomplished by offering incentives for removal to property owners and by incorporating removal of public structures into Capital Improvement Plans. Conditions can also be added to CDPs that require removal of shoreline protection structures after certain thresholds are passed.
Soft protection	"Soft" coastal protection methods replenish, enhance, or mimic natural buffers, and they include beach nourishment, living shorelines, or wetlands. Often most effective where similar soft protection already occurs. Many soft protection methods may also be part of a green infrastructure program.	LCPs can promote the use of soft protection where feasible, through requirements that it be considered whenever shoreline protection is deemed necessary, and through the development of an RSM program that can promote soft solutions. CDP applications should require detailed evaluation of soft options in the alternatives analysis and require the use of soft protection where feasible and consistent with the Coastal Act. Sea-level rise and storms should be incorporated into the siting and design of any soft protection projects.
Waiver of right to shoreline protection	Property owners waive the right to future shoreline protective devices. The waiver specifies that no bluff or shoreline protective device is allowed to protect the development if it is threatened by natural hazards in the future. Instead, development will be removed or relocated if threatened by natural hazards.	As part of a CDP, require property owners to waive their right to future shoreline protection devices. The LCP can contain a policy stating that CDPs should include the waiver as a condition to approval of new development.

4. Coastal Habitats

The coastal habitats category includes measures designed to protect and enhance coastal habitats, including wetlands, ESHA, and other habitats. Some coastal habitat measures include:

- Use of ecological buffer zones
- Incorporation of sea-level rise in restoration, creation, or enhancement of coastal habitats
- Facilitation of wetland migration
- Increased habitat connectivity
- Open space preservation and conservation
- Protection of ecologically critical areas and species
- Protection of refugia

Table 19. Measures for Natural Resources

Category	Description	Applicability to sea-level rise
Ecological buffer zones	Buffer zones are intended to protect sensitive habitats from the adverse impacts of development and human disturbance. An important aspect of buffers is that they are distinct ecologically from the habitat they are designed to protect.	LCPs can establish requirements for ecological buffers and provide guidance on how to establish or adjust these buffers to accommodate sea-level rise. CDPs should require buffers to be designed, where applicable, to provide "habitat migration corridors" that allow sensitive habitats and species to migrate inland or upland as sea level rises. To accommodate sea-level rise, the amount of buffer required between development and coastal habitats may need to be increased. The size of the buffer needed to allow for migration will vary depending on the individual wetland or habitat type, as well as site specific features such as topography and existing development.
Incorporation of sea-level rise in habitat restoration, creation, and enhancement	Restoration involves returning a degraded ecosystem or former ecosystem to a pre-existing condition or as close to that condition as possible. Creation involves converting one land-use type into another, such as converting dry land into a wetland. Enhancement includes increasing one or more of the functions performed by an existing ecosystem beyond what currently or previously existed.	Habitat restoration, creation, or enhancement projects should be designed to withstand impacts of sea-level rise and adapt to future conditions. As applicable, the LCP should contain policies to ensure restoration and management techniques account for future changes in conditions. CDPs for restoration projects should incorporate sea-level rise and provisions to ensure habitats can adapt with changing future conditions.

Facilitation of wetland migration	Reserve space for a "habitat migration corridor," or areas into which wetlands could migrate as sea-level rise induced inundation of existing wetland areas occurs.	In the LCP, identify potential habitat migration corridors. These areas could be reserved for this purpose in an LCP through land acquisition, use designations, zoning buffers, setbacks, conservation easement requirements, and clustering development. LCPs should also consider developing a plan for acquisition of important habitat migration corridors.
Increased habitat connectivity	Connectivity refers to the degree to which the landscape facilitates animal movement and other ecological flows. Roads, highways, median barriers, fences, walls, culverts, and other structures can inhibit movement of animals.	Develop LCP policies that will enable identification of important animal movement corridors. Develop regulations to protect these corridors for present and future conditions, taking into account habitat shifts from climate change. In LCPs and through CDPs, require that new structures such as highways, medians, bridges, culverts, and other development are designed to facilitate movement of animals.
Open space preservation and conservation	This measure involves preservation of land for its ecological or recreational value. It includes prohibiting development and any uses that conflict with ecological preservation goals.	LCPs can develop open space management plans that evaluate and consider the impacts of sea-level rise, extreme events, and other climate change impacts. LCPs and CDPs can dedicate open space and conservation areas through zoning, redevelopment restrictions, acquisition, easements, setbacks, and buffers.
Protection of ecologically critical areas and refugia	Protect ecologically critical areas, or areas that are important for the continued survival of a species or ecosystem (e.g. nursery grounds, spawning areas, or highly diverse areas) that could be adversely affected by sea-level rise. Also, protect refugia, or areas that may be relatively unaltered by global climate change and thus can serve as a refuge for coastal species displaced from their native habitat due to sea-level rise or other climate change impacts.	LCP land use designations and zoning, and standards for buffers, setbacks, and conservation areas can identify and protect refugia and ecologically-critical areas. Such areas can also be preserved through LCP land use designations and zoning, and standards for buffers, setbacks, conservation easements, and clustering development.

5. Water Quality/ Water Supply Management

Water quality and water supply management measures include actions to minimize adverse impacts to water quality due to sea-level rise, and to prepare for reduced availability of freshwater due to saltwater intrusion. Water quality and water supply management measures include:

- Elimination or reduction of ocean outfall
- Green stormwater infrastructure
- Ground water management
- Limited groundwater extraction from shallow aquifers
- Stormwater management

Table 20. Measures for Water Quality/ Water Supply Management

Category	Description	Applicability to sea-level rise
Elimination or reduction of ocean outfalls	An ocean outfall is a pipeline or tunnel that discharges municipal or industrial wastewater, stormwater, combined sewer overflows, cooling water, or brine effluents from desalination plants to the sea.	LCPs should identify areas where sea-level rise could affect flow of wastewater from outfalls and lead to backup and inland flooding. The LCP can include policies to require modifications to the outfall lines, the use of green infrastructure and redesign of waste and stormwater systems. CDPs for ocean outfalls should consider sea-level rise in design.
Green stormwater infrastructure	Employ natural, on-site drainage strategies to minimize the amount of stormwater that flows into pipes or conveyance systems. These strategies include green roofs, permeable pavements, bioretention (i.e. vegetated swales, rain gardens) and cisterns.	LCPs can include policies that require green infrastructure be used whenever possible in lieu of hard structures. Incorporate sea-level rise and extreme storms into the design.
Ground water management	Plan and coordinate monitoring, operation, and administration of a groundwater basin or portion of a groundwater basin with the goal of fostering long-term sustainability of the resource.	The LCP can add policies that specify limits on the use of groundwater. These policies should be made in accordance with other regional water planning efforts, such as Integrated Regional Water Plans. CDPs involving the use of ground water should develop a ground water management plan.

Limited groundwater extraction from shallow aquifers	Groundwater extraction from shallow aquifers can increase susceptibility to saltwater intrusion. Limiting or preventing extraction from vulnerable aquifers can reduce the impacts of saltwater intrusion and preserve fresh groundwater supplies.	LCPs or CDPs can add restrictions to the use of aquifers susceptible to saltwater intrusion and can encourage measures to recharge shallow aquifers that are depleted.
Stormwater management	Control the amount of pollutants, sediments, and nutrients entering water bodies through precipitation-generated runoff.	LCPs should include sea-level rise and extreme storms in stormwater management plans and actions. LCPs and CDPs for stormwater infrastructure should consider sea-level rise. Actions to reduce impacts from higher water levels could include widening drainage ditches, improving carrying and storing capacity of tidally-influenced streams, installing larger pipes and culverts, adding pumps, converting culverts to bridges, creating retention and detention basins, and developing contingency plans for extreme events.

6. Additional Actions

Additional actions include measures that the Coastal Commission recommends local governments or applicants consider to minimize risks from sea-level rise but that fall outside of the regulatory authority of the Coastal Act.

- Acquisition and buyout programs
- Modeling and mapping
- Monitoring
- Outreach and education
- Research and data collection

Table 21. Additional Actions

Category	Description	Applicability to sea-level rise
Acquisition and buyout programs	Acquisition includes the acquiring of land from the individual landowner(s). Structures are typically demolished or relocated, the property is restored, and future development on the land is restricted. Undeveloped lands are conserved as open space or public parks.	LCPs can include policies to encourage the local government to establish an acquisition plan or buyout program to acquire property at risk from flooding or other hazards.

Modeling and mapping	Modeling and mapping are tools for assessing climate change impacts and vulnerabilities within a planning area and illustrating potential outcomes of adaptation actions. Modeling enables analysis of potential impacts to an area under various sea-level rise scenarios. Maps portray how sea-level rise scenarios may intersect with coastal and marine resources, community assets and existing social and environmental vulnerabilities.	LCPs should rely upon the best available science in developing sea level guidance. Toward that end, models and mapping tools can be important for determining sea level hazards, and vulnerabilities and can help evaluate the utility of various adaptation strategies. Examples include the NOAA SLR Viewer, Our Coast Our Future, CoSMoS, and the Sea-Level Affecting Marshes Model.
Monitoring	Collect observations or data over time to track changes in the function or condition of a system.	Where appropriate, LCPs can establish regional monitoring programs to track changes in sea level, shoreline or ecosystem status, and the efficacy of adaptation measures. CDPs can require SLR monitoring programs as a condition of approval for more site-specific concerns. Key indicators may include flooding frequency, erosion rate, wave height, tidal range, vertical land movement, sedimentation rate, water quality, etc.
Outreach and education	Outreach includes provision of information to all stakeholders, and occurs at regular intervals throughout the planning and implementation process. It helps to gain support for planning and action implementation. Education involves systematic instruction, through formal systems such as schools or universities. It is important to include all relevant stakeholders in these processes.	For many people, sea-level rise is a new issue. Information on sea-level rise science and potential consequences may be useful in order for stakeholders to take an active role in updating the LCP for sea-level rise issues, or in the vulnerability and risk assessment efforts.
Research and data collection	Create a research agenda to address key data gaps and better utilize existing information.	Pursue new research to better understand the factors controlling sea-level rise, baseline shoreline conditions, ecosystem responses to sea-level rise, potential impacts and vulnerabilities, and the efficacy of adaptation tools.

APPENDIX D. RESOURCES FOR ADDRESSING SEA-LEVEL RISE IN LOCAL COASTAL PROGRAMS

This section contains lists of guidebooks, guidance documents, and state and local efforts underway to prepare for sea-level rise, including tables on:

- Adaptation Planning and Vulnerability Assessment Guidebooks – Table 22
- Examples of Sea-Level Rise Vulnerability Assessments in California – Table 23
- California State Government Resources – Table 24
- Sea-Level Rise Data and Resource Clearinghouses – Table 25
- Resources for Assessing Adaptation Measures – Table 26
- California Climate Adaptation Plans that Address Sea-Level Rise – Table 27

Table 22. Resources for Adaptation Planning and Vulnerability Assessments

Adaptation Planning Guidebooks	Description	Source
Scanning the Conservation Horizon (Grannis, 2011)	Designed to assist conservation and resource professionals to better plan, execute, and interpret climate change vulnerability assessments.	http://www.georgetownclimate.org/resources/adaptation-tool-kit-sea-level-rise-and-coastal-land-use
Adapting to Sea Level Rise: A Guide for California's Coastal Communities (Russell and Griggs, 2012)	Intended to assist California's coastal managers and community planners in developing adaptation plans for sea-level rise that are suited to their local conditions and communities.	http://calost.org/pdf/announcements/Adapting%20to%20Sea%20Level%20Rise_N%20Russell_G%20Griggs_2012.pdf
California Climate Adaptation Planning Guide (EMA and CNRA, 2012)	Provides a decision-making framework intended for use by local and regional stakeholders to aid in the interpretation of climate science and to develop a systematic rationale for reducing risks caused, or exacerbated, by climate change.	http://resources.ca.gov/climate_adaptation/local_government/adaptation_policy_guide.html
Preparing for Climate Change: A Guidebook for Regional and State Governments (ICLEI, 2007)	Assists decision-makers in a local, regional, or state government prepare for climate change by recommending a detailed, easy-to-understand process for climate change preparedness based on familiar resources and tools.	http://www.icleiusa.org/action-center/planning/adaptation-guidebook/view?searchterm

Table 23. Examples of Sea-Level Rise Vulnerability Assessments in California

Climate Vulnerability Studies	Description	Source
Santa Barbara Sea-Level Rise Vulnerability Study (Griggs and Russell, 2012)	Assesses the vulnerability of the City of Santa Barbara to future sea-level rise and related coastal hazards (by 2050 and 2100) based upon past events, shoreline topography, and exposure to sea-level rise and wave attack. It also evaluates the likely impacts of coastal hazards to specific areas of the City, analyzes their risks and the City's ability to respond, and recommends potential adaptation responses.	http://www.energy.ca.gov/2012publications/CEC-500-2012-039/CEC-500-2012-039.pdf
City of Santa Cruz Climate Change Vulnerability Assessment (Griggs and Haddad, 2011**)**	Delineates and evaluates the likely impacts of future climate change on the city of Santa Cruz, analyzes the risks that these hazards pose for the city, and then recommends potential adaptation responses to reduce the risk and exposure from these hazards in the future.	http://seymourcenter.ucsc.edu/OOB/SCClimateChangeVulnerabilityAssessment.pdf
Developing Climate Adaptation Strategies for San Luis Obispo County: Preliminary Vulnerability Assessment for Social Systems (Moser, 2012)	Describes the likely impacts of climate change on the resources and social systems of San Luis Obispo County, and assesses key areas of vulnerability. Sea-level rise is identified as a major source of risk to fishing, coastal tourism, coastal development, and infrastructure.	http://www.energy.ca.gov/2012publications/CEC-500-2012-054/CEC-500-2012-054.pdf
Monterey Bay Sea Level Rise Vulnerability Study (Monterey Bay National Marine Sanctuary and PWA ESA; In progress)	Will assess potential future impacts from sea-level rise for the Monterey Bay region. The project will estimate the extent of future coastal erosion in Monterey Bay due to accelerated sea-level rise and evaluate areas subjected to coastal flooding by inundation from wave action and/or storm surges. The project will update and refine existing Monterey Bay coastal hazard zones maps (erosion and flooding).	Project scope and grant details: http://scc.ca.gov/webmaster/ftp/pdf/sccbb/2012/1201/20120119Board03D_Monterey_Bay_Sea_Level_Rise.pdf

Table 24. California State Government Resources

State of California Resources	Description	Source
California Climate Change Center's 3rd Assessment	Explores local and statewide vulnerabilities to climate change, highlighting opportunities for taking concrete actions to reduce climate-change impacts	http://www.climatechange.ca.gov/adaptation/third_assessment/
California State Sea-Level Rise Guidance Document	Provides guidance for incorporating sea-level rise projections into planning and decision making for projects in California. Updated to include NRC projections March 2013.	http://www.opc.ca.gov/webmaster/ftp/pdf/docs/2013_SLR_Guidance_Update_FINAL1.pdf
California Climate Adaptation Planning Guide	Provides a decision-making framework intended for use by local and regional stakeholders to aid in the interpretation of climate science and to develop a systematic rationale for reducing risks caused, or exacerbated, by climate change (2012).	http://resources.ca.gov/climate_adaptation/local_government/adaptation_policy_guide.html
2009 California Climate Adaptation Strategy	Summarizes climate change impacts and recommends adaptation strategies across seven sectors: Public Health, Biodiversity and Habitat, Oceans and Coastal Resources, Water, Agriculture, Forestry, and Transportation and Energy. 2012 update should be available by Jan 2013.	http://www.climatechange.ca.gov/adaptation/strategy/index.html

Table 25. Sea-level rise Data and Resource Clearinghouses

Data and resource clearinghouses	Description	Source
California Climate Commons	Offers a point of access to climate change data and related resources, information about the science that produced it, and the opportunity to communicate with others about applying climate change science to conservation in California.	http://climate.calcommons.org/
Climate Adaptation Knowledge Exchange (CAKE)	Provides an online library of climate adaptation case studies and resources, plus ways to connect with an online climate adaptation community/ network.	http://www.cakex.org/
Ecosystem Based Management Tools Network Database	Provides a searchable database of tools available for climate adaptation, conservation planning, sea-level rise impact assessment, etc.	http://www.ebmtoolsdatabase.org/resource/climate-change-vulnerability-assessment-and-adaptation-tools

Table 26. Resources for Assessing Adaptation Measures

Adaptation Strategies	Description	Source
General		
Georgetown Climate Center's Climate Adaptation Toolkit – Sea-Level Rise and Coastal Land Use	Explores 18 different land-use tools that can be used to preemptively respond to the threats posed by sea-level rise to both public and private coastal development and infrastructure, and strives to assist governments in determining which tools to employ to meet their unique socio-economic and political contexts.	http://www.georgetownclimate.org/resources/adaptation-tool-kit-sea-level-rise-and-coastal-land-use
Strategies for Erosion-Related Impacts		
Evaluation of Erosion Mitigation Alternatives for Southern Monterey Bay	Provides a technical evaluation of various erosion mitigation measures, conducts a cost benefit analysis of some of the more promising measures, and includes recommendations for addressing coastal erosion in Southern Monterey Bay. The report is intended to be relevant for other areas of California as well.	http://montereybay.noaa.gov/new/2012/erosion.pdf
Rolling Easements		
Rolling Easements- A Primer (Titus 2011)	Examines more than a dozen different legal approaches to rolling easements. It differentiates opportunities for legislatures, regulators, land trusts, developers, and individual landowners. Considers different shoreline environments (e.g. wetlands, barrier islands) and different objectives (e.g. public access, wetland migration)	http://papers.risingsea.net/rolling-easements.html
No Day at the Beach: Sea Level Rise, Ecosystem Loss, and Public Access Along the California Coast (Caldwell and Segall 2007)	Provides a description of sea-level rise impacts to ecosystems and public access, strategies to address these impacts, and case study examples of rolling easement strategies for the California coast.	http://www.boalt.org/elq/documents/elq34-2-09-caldwell-2007-0910.pdf

Natural Resources		
PRBO Climate Smart Conservation	Lists science-based, climate-smart conservation planning and management tools and methods, including restoration projects designed for climate change and extremes.	http://www.prbo.org/cms/650
US Forest Service System for Assessing Vulnerability of Species- Climate Change Tool	Quantifies the relative impact of expected climate change effects for terrestrial vertebrate species.	http://www.fs.fed.us/rm/grassland-shrubland-desert/products/species-vulnerability/savs-climate-change-tool/

Table 27. California Climate Adaptation Plans that Address Sea-Level Rise

Example Climate Adaptation Plans	Description	Source
Adapting to Rising Tides (ART) Project	The ART project is a collaborative planning effort led by the San Francisco Bay Conservation and Development Commission to help SF Bay Area communities adapt to rising sea levels. The project has started with a vulnerability assessment for a portion of the Alameda County shoreline.	http://www.adaptingtorisingtides.org/ Vulnerability and risk assessment report: http://www.adaptingtorisingtides.org/vulnerability-and-risk-assessment-report/
Santa Cruz Climate Adaptation Plan	An update to the 2007 Hazard Mitigation Plan, the adaptation plan includes strategies and best available science for integrating climate change impacts into City of Santa Cruz operations.	Complete plan is available: http://www.cityofsantacruz.com/Modules/ShowDocument.aspx?documentid=23643
San Diego Bay Sea Level Rise Adaptation Strategy	The strategy provides measures to evaluate and manage risks from sea-level rise and other climate change impacts, and includes a vulnerability assessment of community assets at risk, and broad recommendations to increase resilience of these assets.	http://www.icleiusa.org/climate_and_energy/Climate_Adaptation_Guidance/san-diego-bay-sea-level-rise-adaptation-strategy-1/san-diego-bay-sea-level-rise-adaptation-strategy

APPENDIX E. EXAMPLES OF SEA-LEVEL RISE PREPARATION FROM OTHER STATE AGENCIES

Many state agencies have developed, or are in the process of developing guidance on suggested actions to prepare for sea-level rise relevant to their organization. Some of these guidance documents are described below in Table 28. The table includes a brief description of the documents and the sea-level rise projections used.

Table 28. California State Agency Sea-Level Rise Policy Guidance Documents

Agency	Name and date of document	Description
California Natural Resources Agency	Safeguarding California from Climate Change: update to 2009 Climate Adaptation Strategy	The California Natural Resources Agency, in coordination with other state agencies, is in the process of updating the 2009 Climate Adaptation Strategy. This update will augment previously identified strategies in light of advances in climate science and risk management options. The update is planned for release to the public as a draft for comment by the end of 2013. For more information, visit: http://www.climatechange.ca.gov/adaptation/strategy/index.html
Coasts & Oceans Climate Action Team (led by Ocean Protection Council)	California State Sea-Level Rise Guidance Document (2013)	Provides guidance for incorporating sea-level rise projections into planning and decision making for projects in California. Updated to include NRC projections March 2013. Available: http://www.opc.ca.gov/webmaster/ftp/pdf/docs/2013_SLR_Guidance_Update_FINAL1.pdf
California Coastal Conservancy	Climate Change Policy (2010)	Includes policies on 1) Consideration of climate change in project evaluation 2) Consideration of sea-level rise impacts in vulnerability assessments, 3) Collaboration to support adaptation strategies, 4) Encouragement of adaptation strategies in project applications mitigation and adaptation. Available: http://scc.ca.gov/2009/01/21/coastal-conservancy-climate-change-policy-and-project-selection-criteria/
	Project Selection Criteria (2011)	Adds sea-level rise vulnerability to project selection criteria. Criteria available: http://scc.ca.gov/2009/01/21/coastal-conservancy-climate-change-policy-and-project-selection-criteria/

	Guidance for addressing climate change in CA Coastal Conservancy projects (2012)	Includes the following steps: 1) Conduct initial vulnerability assessment, 2) Conduct more comprehensive vulnerability assessment, 3) Reduce risks and increase adaptive capacity, and 4) Identify adaptation options. Available: http://scc.ca.gov/2013/04/24/guidance-for-grantees
San Francisco Bay Conservation and Development Commission (BCDC)	Climate Change Bay Plan Amendment (2011)	Amends Bay Plan to include policies on climate change and sea-level rise. Policies require 1) a sea-level rise risk assessment for shoreline planning and larger shoreline projects. 2) If risks exist, the project must be designed to cope with flood levels by mid-century, and a plan to address flood risks at end of century. Assessments are required to "identify all types of potential flooding, degrees of uncertainty, consequences of defense failure, and risks to existing habitat from proposed flood protection devices." Available: http://www.bcdc.ca.gov/proposed_bay_plan/bp_amend_1-08.shtml
	"Living with a Rising Bay: Vulnerability and Adaptation in San Francisco Bay and on its Shoreline" (2009)	Provides the background staff report identifying vulnerabilities in the Bay Area's economic and environmental systems, as well as the potential impacts of climate change on public health and safety. The report provides the basis for all versions of the proposed findings and policies concerning climate change. Available: http://www.bcdc.ca.gov/BPA/LivingWithRisingBay.pdf
California Department of Transportation (CalTrans)	CalTrans Climate Change Adaptation Hot Spot Map (in development)	Goal is to create a GIS-based assessment of transportation infrastructure vulnerabilities using available data and studies and to identify critical transportation hotspots (areas of increased vulnerability due to population, travel, or climate effects). This research will also result in the development of a climate vulnerability plan that will assess the level and type of transportation infrastructure vulnerability, the adaptation options and strategies, and a framework for prioritizing implementation efforts (in development). More information available: http://www.dot.ca.gov/hq/tpp/offices/orip/climate_change/projects_and_studies.shtml

	Guidance on Incorporating Sea Level Rise (2011)	Provides guidance on how to incorporate sea-level rise concerns into programming and design of CalTrans projects. Includes screening criteria for determining whether to include SLR and steps for evaluating degree of potential impacts, developing adaptation alternatives, and implementing the adaptation strategies. Available: http://www.dot.ca.gov/ser/downloads/sealevel/guide_incorp_slr.pdf
	Addressing Climate Change in Regional Transportation Plans: A Guide for MPOs and RTPAs (2010)	Provides a clear methodology for regional agencies to address climate change impacts through adaptation of transportation infrastructure. Available: http://www.dot.ca.gov/hq/tpp/offices/orip/climate_change/documents/FR3_CA_Climate_Change_Adaptation_Guide_2013-02-26_.pdf#zoom=65
State Lands Commission	Application for Lease of State Lands (2011)	Requires assessment of climate change risks, and preference is given to projects that reduce climate change risks. Available: http://www.slc.ca.gov/Online_Forms/LMDApplication/Lease_App_Form_2011.pdf
California State Parks	Sea-level rise guidance (in development)	Will provide guidance to Park staff on how to assess impacts to parklands.

APPENDIX F: COASTAL ACT POLICIES RELEVANT TO SEA-LEVEL RISE AND COASTAL HAZARDS

F.1 Legislative Findings Relating to Sea-Level Rise

Section 30006.5 of the Coastal Act states (Legislative findings and declarations; technical advice and recommendations) states (emphasis added):

> *The Legislature further finds and declares that sound and timely scientific recommendations are necessary for many coastal planning, conservation, and development decisions and that the commission should, in addition to developing its own expertise in significant applicable fields of science, interact with members of the scientific and academic communities in the social, physical, and natural sciences so that the commission may receive technical advice and recommendations with regard to its decisionmaking, especially with regard to issues such as coastal erosion and geology, marine biodiversity, wetland restoration, the <u>question of sea-level rise</u>, desalination plants, and the cumulative impact of coastal zone developments.*

F.2 Public Access and Recreation

Section 30210 of the Coastal Act (Access; recreational opportunities; posting) states:

> *In carrying out the requirement of Section 4 of Article X of the California Constitution, maximum access, which shall be conspicuously posted, and recreational opportunities shall be provided for all the people consistent with public safety needs and the need to protect public rights, rights of private property owners, and natural resource areas from overuse.*

Section 30211 of the Coastal Act (Development not to interfere with access) states:

> *Development shall not interfere with the public's right of access to the sea where acquired through use or legislative authorization, including, but not limited to, the use of dry sand and rocky coastal beaches to the first line of terrestrial vegetation.*

Section 30212 of the Coastal Act (New development projects) states:

> *(a) Public access from the nearest public roadway to the shoreline and along the coast shall be provided in new development projects except where: (1) it is inconsistent with public safety, military security needs, or the protection of fragile coastal resources, (2) adequate access exists nearby, or (3) agriculture would be adversely affected. Dedicated accessway shall not be required to be opened to public use until a public agency or private association agrees to accept responsibility for maintenance and liability of the accessway.*

Section 30214 of the Coastal Act (Implementation of public access policies; legislative intent) states:

> (*a) The public access policies of this article shall be implemented in a manner that takes into account the need to regulate the time, place, and manner of public access depending on the facts and circumstances in each case including, but not limited to, the following:*
> *(1) Topographic and geologic site characteristics.*

> *(2) The capacity of the site to sustain use and at what level of intensity.*
>
> *(3) The appropriateness of limiting public access to the right to pass and repass depending on such factors as the fragility of the natural resources in the area and the proximity of the access area to adjacent residential uses.*
>
> *(4) The need to provide for the management of access areas so as to protect the privacy of adjacent property owners and to protect the aesthetic values of the area by providing for the collection of litter.*
>
> *(b) It is the intent of the Legislature that the public access policies of this article be carried out in a reasonable manner that considers the equities and that balances the rights of the individual property owner with the public's constitutional right of access pursuant to Section 4 of Article X of the California Constitution. Nothing in this section or any amendment thereto shall be construed as a limitation on the rights guaranteed to the public under Section 4 of Article X of the California Constitution.*
>
> *(c) In carrying out the public access policies of this article, the commission and any other responsible public agency shall consider and encourage the utilization of innovative access management techniques, including, but not limited to, agreements with private organizations which would minimize management costs and encourage the use of volunteer programs.*

Section 30220 of the Coastal Act (Protection of certain water-oriented activities) states:

> *Coastal areas suited for water-oriented recreational activities that cannot readily be provided at inland water areas shall be protected for such uses.*

Section 30221 of the Coastal Act (Oceanfront land; protection for recreational use and development**)** states:

> *Oceanfront land suitable for recreational use shall be protected for recreational use and development unless present and foreseeable future demand for public or commercial recreational activities that could be accommodated on the property is already adequately provided for in the area.*

Section 30223 of the Coastal Act (Upland areas) states:

> *Upland areas necessary to support coastal recreational uses shall be reserved for such uses, where feasible.*

F.3 Wetlands and Environmentally Sensitive Resources

Section 30231 of the Coastal Act (Biological productivity; water quality) states in part:

> *The biological productivity and the quality of coastal waters, streams, wetlands, estuaries, and lakes appropriate to maintain optimum populations of marine organisms and for the protection of human health shall be maintained and, where feasible, restored…*

Section 30233 (Diking, filling or dredging; continued movement of sediment and nutrients) states:

> *(a) The diking, filling, or dredging of open coastal waters, wetlands, estuaries, and lakes shall be permitted in accordance with other applicable provisions of this division, where there is no feasible less environmentally damaging alternative, and where feasible mitigation measures have been provided to minimize adverse environmental effects, and shall be limited to the following:*

Section 30240 of the Coastal Act (Environmentally sensitive habitat areas; adjacent developments) states:

> *(a) Environmentally sensitive habitat areas shall be protected against any significant disruption of habitat values, and only uses dependent on those resources shall be allowed within those areas.*
>
> *(b) Development in areas adjacent to environmentally sensitive habitat areas and parks and recreation areas shall be sited and designed to prevent impacts which would significantly degrade those areas, and shall be compatible with the continuance of those habitat and recreation areas.*

Coastal Act Section 30121 defines "Wetland" as follows:

> *"Wetland" means lands within the coastal zone which may be covered periodically or permanently with shallow water and include saltwater marshes, freshwater marshes, open or closed brackish water marshes, swamps, mudflats, and fens.*

The California Code of Regulations Section 13577(b) of Title 14, Division 5.5, Article 18 defines "Wetland" as follows:

> *(1) Measure 100 feet landward from the upland limit of the wetland. Wetland shall be defined as land where the water table is at, near, or above the land surface long enough to promote the formation of hydric soils or to support the growth of hydrophytes, and shall also include those types of wetlands where vegetation is lacking and soil is poorly developed or absent as a result of frequent and drastic fluctuations of surface water levels, wave action, water flow, turbidity or high concentrations of salts or other substances in the substrate. Such wetlands can be recognized by the presence of surface water or saturated substrate at some time during each year and their location within, or adjacent to, vegetated wetlands or deep-water habitats. For purposes of this section, the upland limit of a wetland shall be defined as:*
>
> > *(A) the boundary between land with predominantly hydrophytic cover and land with predominantly mesophytic or xerophytic cover;*
> > *(B) the boundary between soil that is predominantly hydric and soil that is predominantly nonhydric; or*
> > *(C) in the case of wetlands without vegetation or soils, the boundary between land that is flooded or saturated at some time during years of normal precipitation, and land that is not.*
>
> *(2) For the purposes of this section, the term "wetland" shall not include wetland habitat created by the presence of and associated with agricultural ponds and reservoirs where:*
>
> > *(A) the pond or reservoir was in fact constructed by a farmer or rancher for agricultural purposes; and*
> > *(B) there is no evidence (e.g., aerial photographs, historical survey, etc.) showing that*

> *wetland habitat pre-dated the existence of the pond or reservoir. Areas with drained hydric soils that are no longer capable of supporting hydrophytes shall not be considered wetlands.*

In addition, Coastal Act Section 30107.5 defines "Environmentally sensitive area" as follows:

> *"Environmentally sensitive area" means any area in which plant or animal life or their habitats are either rare or especially valuable because of their special nature or role in an ecosystem and which could be easily disturbed or degraded by human activities and developments.*

F.4 Agricultural and Timber Lands

Section 30241 of the Coastal Act (Prime agricultural land; maintenance in agricultural production) states:

> *The maximum amount of prime agricultural land shall be maintained in agricultural production to assure the protection of the areas' agricultural economy, and conflicts shall be minimized between agricultural and urban land uses…*

Section 30242 of the Coastal Act (Lands suitable for agricultural use; conversion) states:

> *All other lands suitable for agricultural use shall not be converted to nonagricultural uses unless (1) continued or renewed agriculture use is not feasible, or (2) such conversion would preserve prime agricultural land or concentrate development consistent with Section 30250. Any such permitted conversion shall be compatible with continue agricultural use on surrounding lands.*

Section 30243 of the Coastal Act (Productivity of soils and timberlands; conversions) states:

> *The long-term productivity of soils and timberlands shall be protected, and conversions of coastal commercial timberlands in units of commercial size to other uses or their division into units of noncommercial size shall be limited to providing for necessary timber processing and related facilities.*

F.5 Archeological and Paleontological Resources

Section 30244 of the Coastal Act (Archaeological or paleontological resources) states:

> *Where development would adversely impact archaeological or paleontological resources as identified by the State Historic Preservation Officer, reasonable mitigation measures shall be required.*

F.6 Marine Resources

Section 30230 of the Coastal Act (Marine resources; maintenance) states:

> *Marine resources shall be maintained, enhanced, and where feasible, restored. Special protection shall be given to areas and species of special biological or economic significance. Uses of the marine environment shall be carried out in a manner that will sustain the biological productivity of coastal waters and that will maintain healthy*

populations of all species of marine organisms adequate for long-term commercial, recreational, scientific, and educational purposes.

Section 30231 of the Coastal Act (Biological productivity; water quality) states:

The biological productivity and the quality of coastal waters, streams, wetlands, estuaries, and lakes appropriate to maintain optimum populations of marine organisms and for the protection of human health shall be maintained and, where feasible, restored through, among other means, minimizing adverse effects of waste water discharges and entrainment, controlling runoff, preventing depletion of ground water supplies and substantial interference with surface waterflow, encouraging waste water reclamation, maintaining natural vegetation buffer areas that protect riparian habitats, and minimizing alteration of natural streams.

Section 30233 of the Coastal Act (Diking, filling or dredging; continued movement of sediment and nutrients) states:

(a) The diking, filling, or dredging of open coastal waters, wetlands, estuaries, and lakes shall be permitted in accordance with other applicable provisions of this division, where there is no feasible less environmentally damaging alternative, and where feasible mitigation measures have been provided to minimize adverse environmental effects…

(d) Erosion control and flood control facilities constructed on watercourses can impede the movement of sediment and nutrients that would otherwise be carried by storm runoff into coastal waters. To facilitate the continued delivery of these sediments to the littoral zone, whenever feasible, the material removed from these facilities may be placed at appropriate points on the shoreline in accordance with other applicable provisions of this division, where feasible mitigation measures have been provided to minimize adverse environmental effects. Aspects that shall be considered before issuing a coastal development permit for these purposes are the method of placement, time of year of placement, and sensitivity of the placement area.

Section 30234 of the Coastal Act (Commercial fishing and recreational boating facilities**)** states:

Facilities serving the commercial fishing and recreational boating industries shall be protected and, where feasible, upgraded. Existing commercial fishing and recreational boating harbor space shall not be reduced unless the demand for those facilities no longer exists or adequate substitute space has been provided. Proposed recreational boating facilities shall, where feasible, be designed and located in such a fashion as not to interfere with the needs of the commercial fishing industry.

Section 30234.5 of the Coastal Act (Economic, commercial, and recreational importance of fishing) states:

The economic, commercial, and recreational importance of fishing activities shall be recognized and protected.

F.7 Coastal Development

Section 30250 of the Coastal Act (Location; existing developed area) states:

> *(a) New residential, commercial, or industrial development, except as otherwise provided in this division, shall be located within, contiguous with, or in close proximity to, existing developed areas able to accommodate it or, where such areas are not able to accommodate it, in other areas with adequate public services and where it will not have significant adverse effects, either individually or cumulatively, on coastal resources. In addition, land divisions, other than leases for agricultural uses, outside existing developed areas shall be permitted only where 50 percent of the usable parcels in the area have been developed and the created parcels would be no smaller than the average size of surrounding parcels.*
> *(b) Where feasible, new hazardous industrial development shall be located away from existing developed areas.*
> *(c) Visitor-serving facilities that cannot feasibly be located in existing developed areas shall be located in existing isolated developments or at selected points of attraction for visitors.*

Section 30251 of the Coastal Act (Scenic and visual qualities) states:

> *The scenic and visual qualities of coastal areas shall be considered and protected as a resource of public importance. Permitted development shall be sited and designed to protect views to and along the ocean and scenic coastal areas, to minimize the alteration of natural land forms, to be visually compatible with the character of surrounding areas, and, where feasible, to restore and enhance visual quality in visually degraded areas...*

Section 30253 the Coastal Act (Minimization of adverse impacts) states in part:

> *New development shall do all of the following:*
> *(a) Minimize risks to life and property in areas of high geologic, flood, and fire hazard.*
> *(b) Assure stability and structural integrity, and neither create nor contribute significantly to erosion, geologic instability, or destruction of the site or surrounding area or in any way require the construction of protective devices that would substantially alter natural landforms along bluffs and cliffs...*

Section 30235 of the Coastal Act (Construction altering natural shoreline) states:

> *Revetments, breakwaters, groins, harbor channels, seawalls, cliff retaining walls, and other such construction that alters natural shoreline processes shall be permitted when required to serve coastal-dependent uses or to protect existing structures or public beaches in danger from erosion, and when designed to eliminate or mitigate adverse impacts on local shoreline sand supply. Existing marine structures causing water stagnation contributing to pollution problems and fishkills should be phased out or upgraded where feasible.*

Section 30236 of the Coastal Act (Water supply and flood control) states:

> *Channelizations, dams, or other substantial alterations of rivers and streams shall incorporate the best mitigation measures feasible, and be limited to (l) necessary water supply projects, (2) flood control projects where no other method for protecting existing structures in the flood plain is feasible and where such protection is necessary for public safety or to protect existing development, or (3) developments where the primary function is the improvement of fish and wildlife habitat.*

F.8 Ports

Section 30705 of the Coastal Act (Diking, filling or dredging water areas) states:

> *(a) Water areas may be diked, filled, or dredged when consistent with a certified port master plan only for the following: …*
>
> *(b) The design and location of new or expanded facilities shall, to the extent practicable, take advantage of existing water depths, water circulation, siltation patterns, and means available to reduce controllable sedimentation so as to diminish the need for future dredging.*
>
> *(c) Dredging shall be planned, scheduled, and carried out to minimize disruption to fish and bird breeding and migrations, marine habitats, and water circulation. Bottom sediments or sediment elutriate shall be analyzed for toxicants prior to dredging or mining, and where water quality standards are met, dredge spoils may be deposited in open coastal water sites designated to minimize potential adverse impacts on marine organisms, or in confined coastal waters designated as fill sites by the master plan where such spoil can be isolated and contained, or in fill basins on upland sites. Dredge material shall not be transported from coastal waters into estuarine or fresh water areas for disposal.*

Section 30706 of the Coastal Act (Fill) states:

> *In addition to the other provisions of this chapter, the policies contained in this section shall govern filling seaward of the mean high tide line within the jurisdiction of ports:*
>
> > *(a) The water area to be filled shall be the minimum necessary to achieve the purpose of the fill.*
> >
> > *(b) The nature, location, and extent of any fill, including the disposal of dredge spoils within an area designated for fill, shall minimize harmful effects to coastal resources, such as water quality, fish or wildlife resources, recreational resources, or sand transport systems, and shall minimize reductions of the volume, surface area, or circulation of water.*
> >
> > *(c) The fill is constructed in accordance with sound safety standards which will afford reasonable protection to persons and property against the hazards of unstable geologic or soil conditions or of flood or storm waters.*
> >
> > *(d) The fill is consistent with navigational safety.*

Section 30708 of the Coastal Act (Location, design and construction of port related developments) states:

> *All port-related developments shall be located, designed, and constructed so as to:*
>
> > *(a) Minimize substantial adverse environmental impacts.*
> >
> > *(b) Minimize potential traffic conflicts between vessels.*
> >
> > *(c) Give highest priority to the use of existing land space within harbors for port purposes, including, but not limited to, navigational facilities, shipping industries, and necessary support and access facilities.*
> >
> > *(d) Provide for other beneficial uses consistent with the public trust, including, but not limited to, recreation and wildlife habitat uses, to the extent feasible.*
> >
> > *(e) Encourage rail service to port areas and multicompany use of facilities.*

F.9 Public Works Facilities

According to Coastal Act Section 30114, public works facilities includes:

> *(a) All production, storage, transmission, and recovery facilities for water, sewerage, telephone, and other similar utilities owned or operated by any public agency or by any utility subject to the jurisdiction of the Public Utilities Commission, except for except for energy facilities [which are regulated by the Public Utilities Commission].*
>
> *(b) All public transportation facilities, including streets, roads, highways, public parking lots and structures, ports, harbors, airports, railroads, and mass transit facilities and stations, bridges, trolley wires, and other related facilities. For purposes of this division, neither the Ports of Hueneme, Long Beach, Los Angeles, nor San Diego Unified Port District nor any of the developments within these ports shall be considered public works.*
> *(c) All publicly financed recreational facilities, all projects of the State Coastal Conservancy, and any development by a special district.*
> *(d) All community college facilities.*

F.10 Greenhouse Gas Emissions Reduction

Section 30250(a) of the Coastal Act (Location, existing developed areas states) in part:

> *(a) New residential, commercial, or industrial development, except as otherwise provided in this division, shall be located within, contiguous with, or in close proximity to, existing developed areas able to accommodate it or, where such areas are not able to accommodate it, in other areas with adequate public services and where it will not have significant adverse effects, either individually or cumulatively, on coastal resources. In addition, land divisions, other than leases for agricultural uses, outside existing developed areas shall be permitted only where 50 percent of the usable parcels in the area have been developed and the created parcels would be no smaller than the average size of surrounding parcels.*

Section 30252 of the Coastal Act (Maintenance and enhancement of public access) states:

> *The location and amount of new development should maintain and enhance public access to the coast by (1) facilitating the provision or extension of transit service, (2) providing commercial facilities within or adjoining residential development or in other areas that will minimize the use of coastal access roads, (3) providing nonautomobile circulation within the development, (4) providing adequate parking facilities or providing substitute means of serving the development with public transportation, (5) assuring the potential for public transit for high intensity uses such as high-rise office buildings, and by (6) assuring that the recreational needs of new residents will not overload nearby coastal recreation areas by correlating the amount of development with local park acquisition and development plans with the provision of onsite recreational facilities to serve the new development.*

Section 30253(d) of the Coastal Act (Minimization of adverse impacts) states in part:

> *New Development shall:*

(d) Minimize energy consumption and vehicle miles traveled….